

Appendix E

Evaluation of Groundwater Protection

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Terms

2-D	two-dimensional
3-D	three-dimensional
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
CT	carbon tetrachloride
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i>
CFR	<i>Code of Federal Regulations</i>
COPC	contaminant of potential concern
DAF	dilution attenuation factor
DOD	Department of Defense
DOE	U.S. Department of Energy
DNAPL	dense, nonaqueous-phase liquid
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
EVSDS	Effluent Volume to Soil Disposal Sites
FEP	feature, event, and process
HEIS	Hanford Environmental Information System
K _d	partitioning coefficient
LTRR	long-term recharge rates
MCL	maximum contaminant level
MDA	method detection activity
MDL	method detection limit
OU	operable unit
PCE	tetrachloroethylene
PNNL	Pacific Northwest National Laboratory
PoCal	point of calculation
PQL	practical quantitation limit

QA	quality assurance
QC	quality control
RI	remedial investigation
RIFAT	Remedial Investigation Report Full Analytical Tables
RISAT	Remedial Investigation Report Summary Analytical Tables
SSL	soil screening level
STOMP	Subsurface Transport Over Multiple Phases
SVE	soil vapor extraction
TCE	trichloroethylene
UCL	upper confidence limit
VOA	volatile organic analyte
VOC	volatile organic compound
WAC	<i>Washington Administrative Code</i>

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E1.0 Introduction

This appendix provides an understanding of the potential contaminants of potential concern (COPCs) that may affect groundwater at the 200-PW-1, 200-PW-3, and 200-PW-6 (200-PW-1/3/6) operable unit (OU) sites.

E1.1 Background

The “National Oil and Hazardous Substances Pollution Contingency Plan” (40 *Code of Federal Regulations* [CFR] 300, Subchapter J) requires that a baseline risk assessment be conducted to “characterize the current and potential threats to human health and the environment” [40 CFR 300.430(d)(4), “Remedial Investigation/Feasibility Study and Selection of Remedy”]. The environment is defined in 40 CFR 300 as:

the navigable waters, the waters of the contiguous zone and the ocean waters of which the natural resources are under the exclusive management authority of the United States under the *Magnusen-Stevens Fishery Conservation and Management Act* of 1966, (16 USC 1801, et seq.); and any other surface water, groundwater, drinking water supply, land surface or subsurface strata, or ambient air within the United States or under jurisdiction of the United States.

The baseline risk assessments performed for *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) sites generally conform to EPA/540/1-89/002, *Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A): Interim Final*, and 63 FR 26846, “Guidelines for Ecological Risk Assessment; Notice.” These guidance documents focus on the protection of human health and ecological receptors and do not specifically address protection of groundwater from potential future impacts from vadose zone sources. Currently, no CERCLA guidance document is available that specifically addresses risk assessment criteria and methods to assess the protection of groundwater from potential future impacts from vadose zone sources. Additionally, the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) expect that remedial actions will be protective of groundwater and that the U.S. Department of Energy (DOE) will take steps necessary to prevent further degradation of groundwater (DOE/RL-2002-59, *Hanford Site Groundwater Strategy: Protection, Monitoring, and Remediation*).

E1.2 Screening and Evaluation of Groundwater Protection Contaminants of Potential Concern

A summary of human health risks from direct contact with the COPCs identified for the 200-PW-1/3/6 OUs in DOE/RL-2006-51, *Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units* (RI Report), is presented in Section E3.2 of this report. To evaluate potential future human health concerns in groundwater from the 200-PW-1/3/6 OUs contaminants, soil contaminant data from boreholes proximal to the waste sites considered representative for the evaluation of groundwater protection at the 200-PW-1/3/6 OUs were evaluated. These representative waste sites include the 216-Z-9 Trench/Crib, the 216-Z-1A Tile Field/Crib, the 216-Z-18 Crib, the 216-Z-8 French Drain, and 216-A-8 Crib. Figure E1-1 shows the locations of the Z-Area waste sites in the 200-PW-1 and 200-PW-6 OUs. Figure E1-2 shows the location of the 216-A-8 waste site in the 200-PW-3 OU. Section E2.1.1 describes the borehole data sources of the soil data.

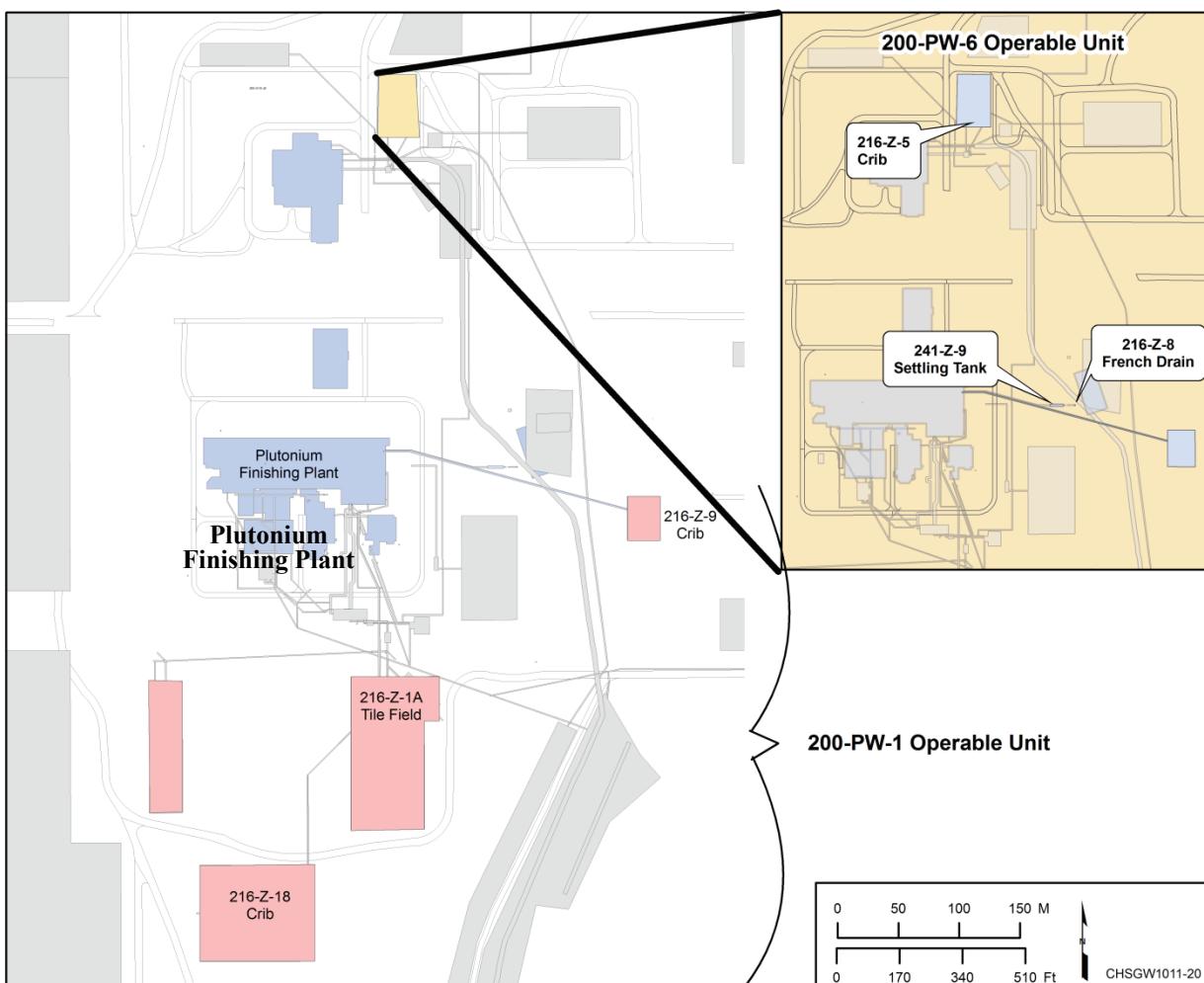


Figure E1-1. Locations of the 200-PW-1 and 200-PW-6 Waste Sites in the 200 West Area

The COPC selection process used for groundwater protection differs somewhat from the COPC selection process used to evaluate the direct contact exposure pathway for a number of reasons:

- The data represent single or duplicate analyses of contaminants in discrete geologic host materials in the subsurface vertically, at specified depth intervals.
- The data represent stratified and systematic random sample populations rather than strictly random sample populations.
- Contaminant reduction in soils, especially deep vadose zone soils, by, e.g., surficial removal methods, may not be practical or cost effective, thus requiring consideration of other remedial actions designed to affect the fate and transport of contaminants to groundwater.
- There is typically no subsequent post-remedy verification sampling data available.
- The screened COPC data serve as the primary basis for defining the contaminant source term in risk characterization using fate and transport modeling.

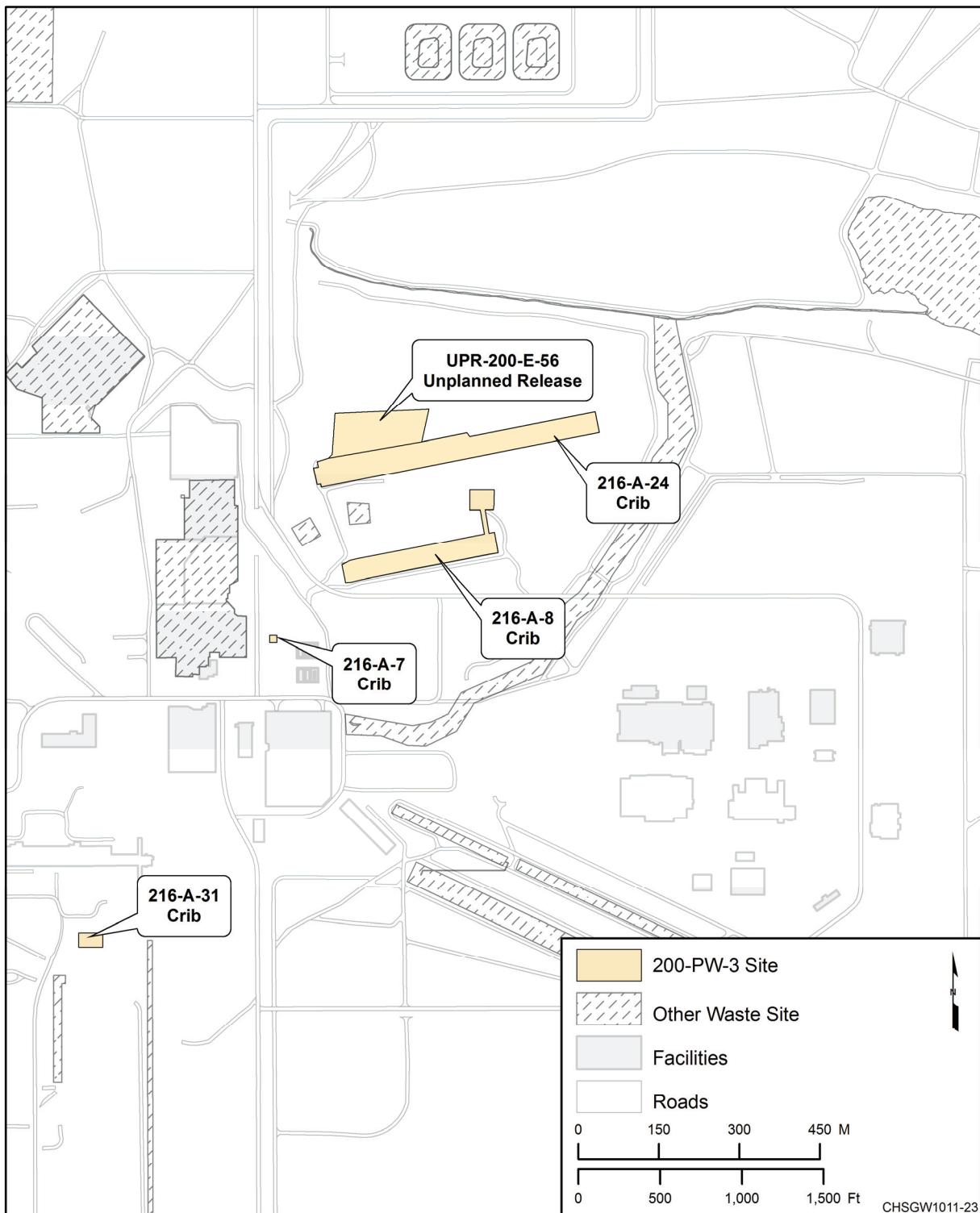


Figure E1-2. Location of the 216-A-8 Crib in the 200-PW-3 Operable Unit Waste Sites of the 200 East Area

These distinctions are important because the determination of whether contamination exists in the subsurface is generally evaluated only once for vadose zone soil data. The objectives of the evaluation of vadose zone COPCs involve assessing the existence of any contamination in the vadose zone soils, and minimizing the uncertainty associated with identifying the presence or absence of contamination in this one and only evaluation. This objective differs from that of traditional EPA soil screening, which is intended to serve as a streamlined evaluation tool to help site managers expedite the elimination of areas, pathways, and/or contaminants of concern, thereby enabling the identification of areas needing further investigation (EPA 540/R-96/018, *Soil Screening Guidance: Users Guide*). The EPA soil screening level (SSL) methodology was designed for use during the early stages of a site evaluation when information about subsurface conditions may be limited, is based on conservative, simplifying assumptions (EPA 540/R-96/018). This process is, therefore, more aptly regarded as a COPC “evaluation” process vs. a traditional COPC “screening” process, which typically involves the application of more complete evaluation measure in subsequent evaluation efforts (e.g., verification sampling). Thus, more complete and robust measures to minimize uncertainties associated with identifying the presence or absence of contamination in the context of Type I and Type II errors are warranted for the process of contaminant identification in vadose zone soil data for groundwater protection. Therefore, the measures utilized in the COPC evaluation process for vadose zone soils include greater levels of scrutiny and rigor in the evaluation of data in the context of, for example, detection, if it is quantifiable (e.g., practical quantitation limits [PQLs]), outliers/exceedances, the use of site data in lieu of default values, and/or other measures that may extend beyond those used in traditional soil screening.

It is also important that robust measures in the COPC “evaluation” of vadose zone soil data be employed prior to the fate and transport modeling phase. Less rigor in the identification of COPCs not only passes reducible uncertainties to the risk characterization evaluation, but also exacerbates those uncertainties by creating unnecessary confusion and challenges for the evaluation of model results when reducible uncertainties are incorporated in the contaminant source term, and attempt to be interpreted in the context of model results for groundwater impacts. Thus, all appropriate measures for minimizing reducible uncertainties in the identification of vadose zone contamination are most appropriately employed prior to the fate and transport modeling phase of the COPC evaluation process. Therefore, the identification COPC evaluation process for vadose zone soils must involve a process that is more rigorous, complete, and even less conservative than the soil screening processes intended to be accompanied by verification sampling following remedial actions. Thus, all measures to reduce uncertainties associated with correctly identifying subsurface soil contamination must be employed in this COPC evaluation process.

The process used in the COPC soil evaluation from boreholes proximal to the 200-PW-1/3/6 waste sites for groundwater protection involved three phases of evaluation, which are described in the following section. The following sections describe the process used in the identification of COPC in soil samples from boreholes near the 200-PW-1/3/6 waste sites selected for the evaluation of groundwater protection. Chapter E4.0 describes the results of the evaluation process, the methodology used to calculate soil source term concentrations for each COPC evaluated in the fate and transport modeling phase of the protection of groundwater COPC evaluation process.

E2.0 COPC Screening and Evaluation Processes

All analytes reported in the analyses of soil samples from all boreholes proximal to the 200-PW-1/3/6 waste sites selected for evaluating groundwater protection were evaluated as COPCs. These analytes included non-radioactive metal, volatile organic compounds (VOCs), semi-volatile compounds, anionic species (e.g., nitrate), and radionuclides. The waste sites included in the evaluation were those considered to have the potential to affect groundwater based on the operations, waste disposal practices, and waste streams. Although the 216-Z-1A is regarded as a waste site, the 216-Z-18 Crib was included in the evaluation because it appeared that there were some COPCs in the subsurface soils associated with this waste site that were not identified in the soils for the 216-Z-1A Crib; therefore, the 216-Z-18 Crib was included in the evaluation for completeness.

The COPC screening and evaluation process involved two main phases of contaminant data screening to identify contaminants in the vadose zone soils to be evaluated in vadose zone fate and transport modeling for risk characterization. Phase I involved an initial screening comparing the maximum detected concentrations of all analytes in the borehole samples from each waste site to the lower of the EPA SSLs (EPA/540/R-95/128), or the soil concentrations for groundwater protection, based on the Fixed Parameter three-phase partitioning model (*Washington Administrative Code [WAC] 173-340-747[3][a]*, “Model Toxics Control Act—Cleanup,” “Deriving Soil Concentrations for Ground Water Protection,” Equation 747-1). Phase II involved screening all data for each COPC remaining from the Phase I screen in a succession of steps that included the following criteria:

1. Laboratory code
2. Background (as appropriate), and/or a soil screening level for groundwater protection based on the EPA Soil-Water partition equation (EPA/540/R-95/128, *Soil Screening Guidance: Technical Background Document*), and use of the parameters in the Ecology Fixed Parameter three-phase partitioning equation (WAC 173-340-747, Equation 747-1)
3. Background (as appropriate), and/or a soil screening level for groundwater protection based on the EPA Soil-Water partition equation (EPA/540/R-95/128), and use of the parameters in the Ecology Fixed Parameter three-phase partitioning equation (WAC-173-340-747, Equation 747-1)
4. Quantitation limit and pathway considerations
5. Evaluation of data anomalies (quality assurance/quality control [QA/QC] check), and other considerations
6. Contaminant transport time to groundwater and consideration of radionuclide decay time (as appropriate)

Data for COPCs passing all screening phases were then used to calculate source term concentrations of contaminated soil volumes evaluated for risk characterization evaluations using vadose zone fate and transport modeling. Figure E2-1 illustrates a schematic summary of this sequence of screening and evaluation phases and steps, which is described in ECF-200PW1/3/6-10-0346, *200-PW-1/3/6 COPC Screening and Evaluation Phases*. Chapter E3.0 reports the progressive results of each phase of the screening evaluation process are. Chapter E4.0 summarizes the modeling results and associated candidate COCs for each waste site. Chapter E5.0 presents the uncertainty analysis and evaluation of the model results. Figures E2-1, E2-2, and E2-3 illustrate schematic summaries of this sequence of screening and evaluation phases and steps.

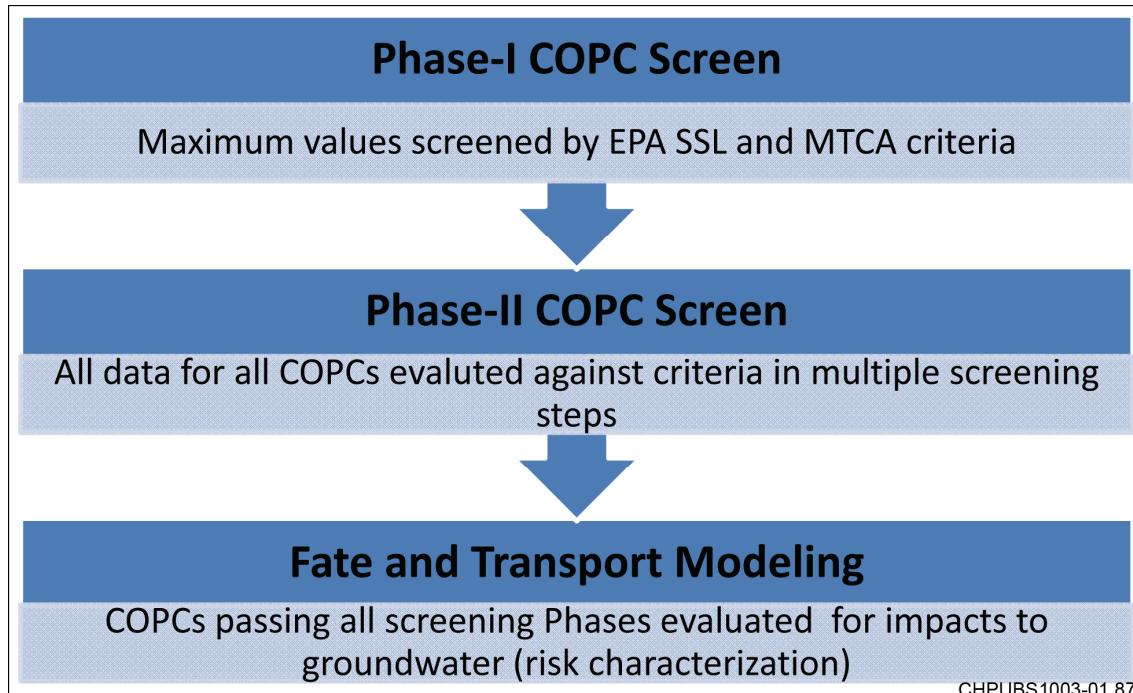


Figure E2-1. Schematic Sequence of the Overall Process of COPC Screening and Evaluation and Model Based Risk Characterization for Groundwater Protection

E2.1 Borehole Data Sources and Analytical Data Processing

Analytical data sets for each borehole or boring were extracted from the Hanford Environment Information System (HEIS) database and the Remedial Investigation Report Full Analytical Tables (RIFAT) and Remedial Investigation Report Summary Analytical Tables (RISAT) reports generated for each waste site as documented in ECF-200-PW1/3/6-10-0360, *Identification of Contaminants of Potential Concern for the 200-PW-1/3/6 Operable Unit*.

All soil samples from soil borings for a waste site are combined to evaluate the groundwater protection pathway. The deep zone (or vadose zone) soil, where the soil surface is 0 m (0 ft) below ground surface (bgs) to the water table, is used to evaluate the potential impacts to groundwater beneath the site from vadose zone contaminants. Table E2-1 identifies boreholes, borings, and other sources of soil data used in the COPC selection process by waste site. Only waste sites with COPCs passing the initial screening phase are listed. The boreholes and borings serving as the source of soil data for COPCs at the 216-Z-1A, 216-Z-18, and 216-Z-9 waste sites identified in Table E2-1 are shown in the context of the waste site locations in Figures E2-4 and E2-5a and b.

Forty-one (41) boreholes within 50 m (164 ft) of the 216-Z-9 waste site with data on chemical and/or radiological analytes were evaluated for inclusion in the COPC screening process. These boreholes represent subsurface sampling and analysis efforts that range in time from 1992 to 2006. The data from six of these boreholes (299-W15-216, -217, -218, -219, -220, and -223) were collected in 1992 to 1993. The data from one borehole (299-W15-46) was collected in 2004. The data from two of the boreholes (299-W-15-84 and 299-15-95) were collected in 2001. All other data from the remaining 31 boreholes/subsurface borings at 216-Z-9 were collected in 2006.

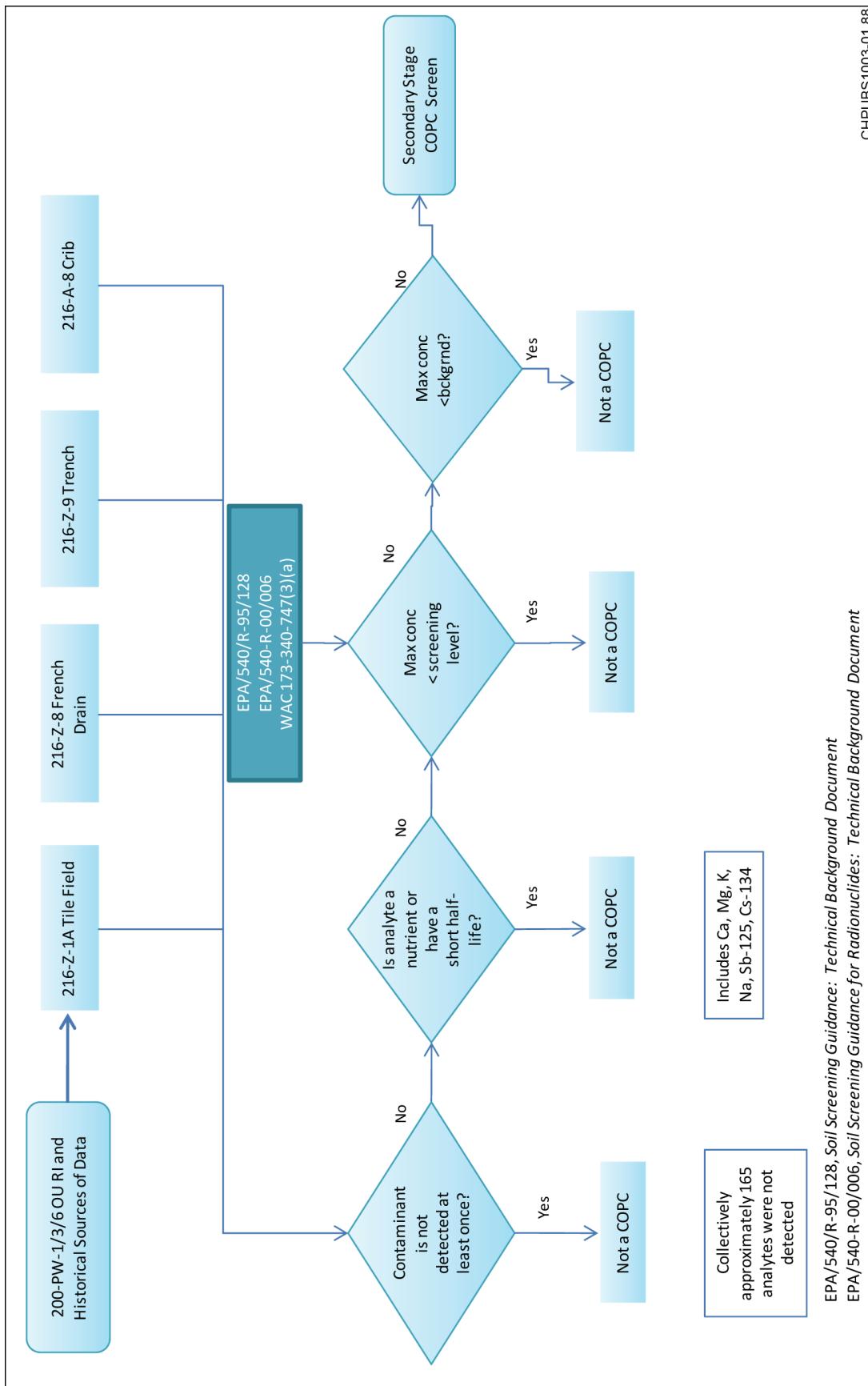


Figure E2-2. Flow Diagram of the Initial Phase (Phase I) of the COPC Screening Process for Groundwater Protection

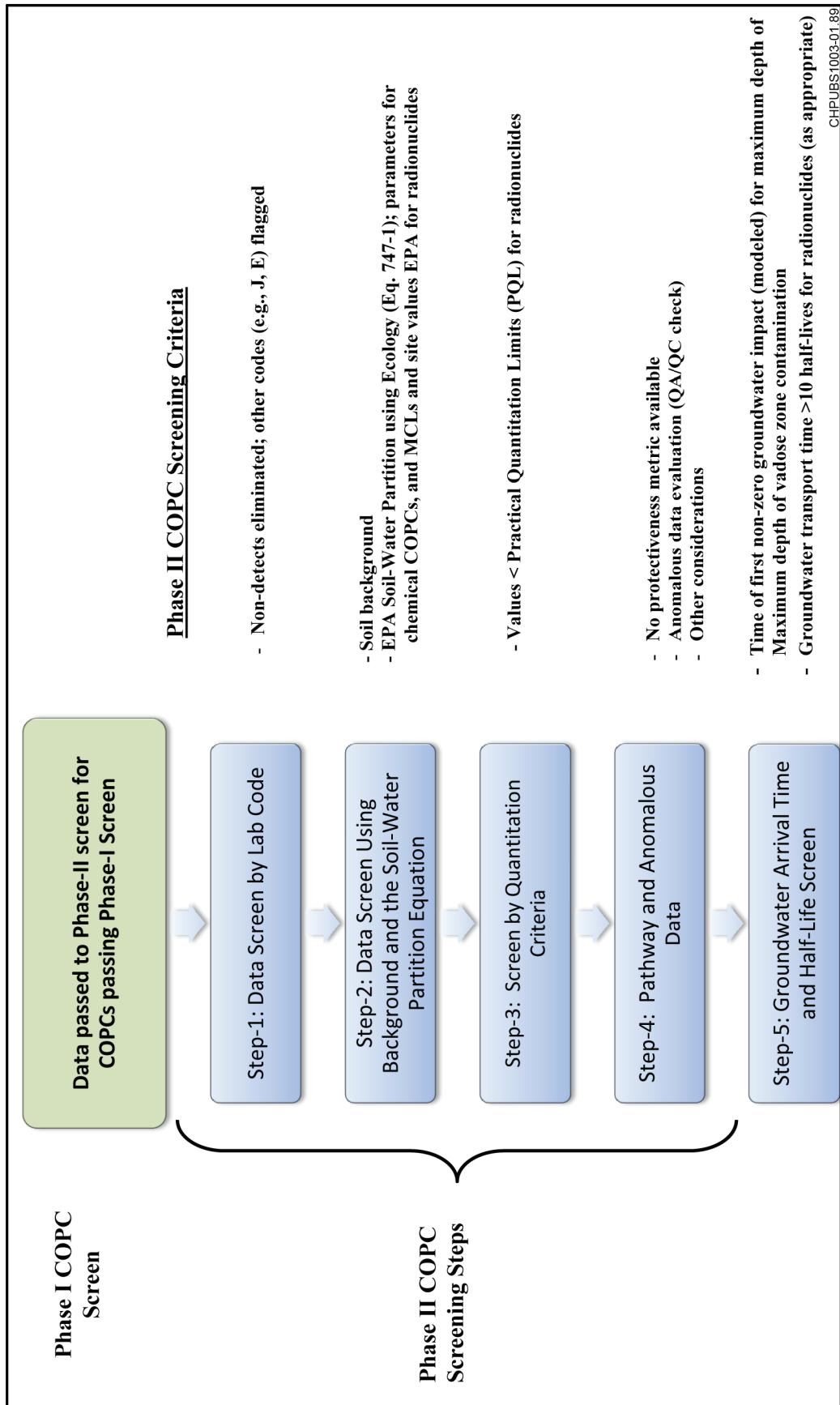


Figure E2-3. Flow Diagram for the Screening Steps and Criteria Associated with Data Screening in the Phase II COPC Screening Process

Table E2-1. Boreholes, Boring, and Other Sources of Soil Samples and Data Used in the COPC Screening Process

Waste Site	Boreholes				
216-Z-1A Tile Fields	299-W18-174	299-W18-246	299-W18-248		299-W18-252 ^a
	299-W18-85	299-W18-86	299-W18-87	299-W18-88	299-W18-149
216-Z-1A Tile Fields (plutonium and americium) ^b	299-W18-150	299-W18-158	299-W18-159	299-W18-163	299-W18-164
	299-W18-165	299-W18-166	299-W18-167	299-W18-168	299-W18-169
	299-W18-171	299-W18-172	299-W18-173	299-W18-174	299-W18-175
216-Z-8 French Drain	216-W15-202				
	299-W15-216	299-W15-95	C5225	C5239	C5336
	299-W15-217	C5198	C5226	C5240	C5337
	299-W15-218	C5199	C5227	C5241	C5338
	299-W15-219	C5200	C5228	C5242	C5339
216-Z-9 Trench	299-W15-220	C5201	C5229	C5327	CPT-16
	299-W15-223	C5202	C5231	C5328	
	299-W15-46	C5203	C5236	C5329	
	299-W15-48	C5206	C5237	C5332	
	299-W15-84	C5223	C5238	C5335	
216-A-8 Crib	C4545				
216-Z-18 Crib	299-W18-247	299-W18-96			299-W18-249
216-Z-361 Settling Tank	NA				
216-Z-10 Injection / Reverse Well	NA				

Notes:

Only waste sites with COPCs passing the initial screening phase are listed.

a. Borehole used for Phase I of COPC screening, but regarded as too distant (>50m) from 216-Z-1A Crib for consideration in Phase II COPC screening (see Table E3-2).

b. Plutonium and americium data only (RHO-ST-17, *Distribution of Plutonium and Americium Beneath the 216-Z-1A Crib: A Status Report*)

NA = Not applicable. The 216-Z-361 Settling Tank had no detected COPCs; the Injection/Reverse Well did not have any samples.

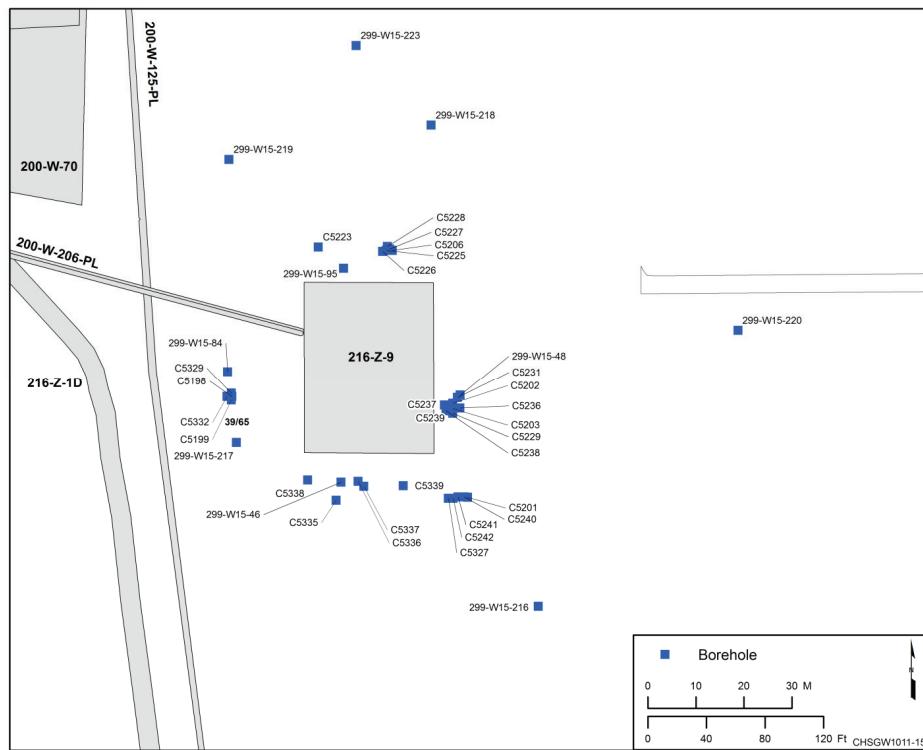


Figure E2-4. Borehole and Boring Locations Serving as the Sources of Samples and Data for 216-Z-9

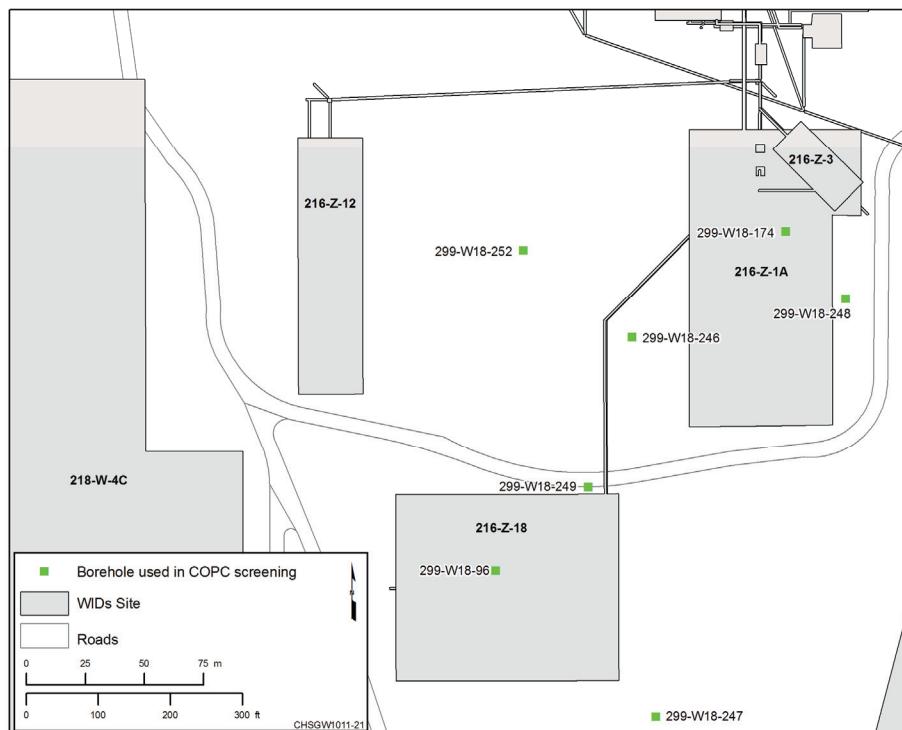


Figure E2-5a. Locations of Boreholes Serving as the Sources of Non-Radiological Samples and Data near the 216-Z-1A and 216-Z-18 Cribs

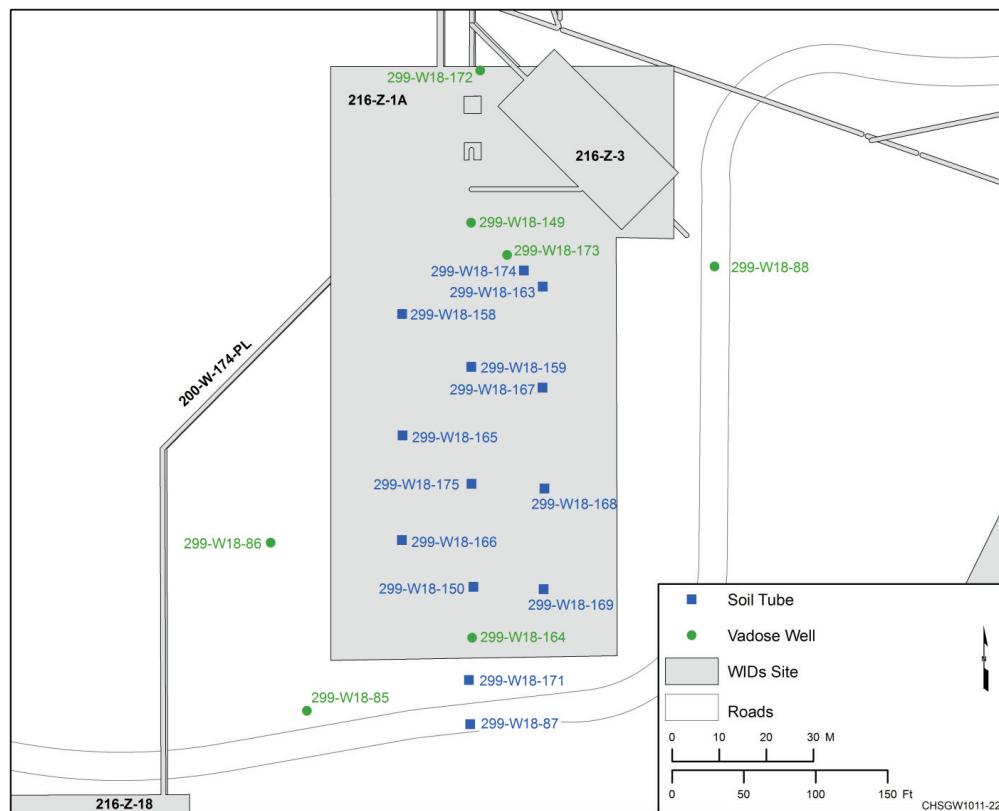


Figure E2-5b. Locations of Boreholes Serving as the Sources of Plutonium and Americium Samples and Data near the 216-Z-1A Crib

These sampling efforts constitute distinct timeframe intervals, beginning in 1992 to 1993 just prior to the initiation of the soil vapor extraction (SVE) system, to 2006, after about 13 years of SVE operation. The levels of VOCs have decreased over time during the course of SVE operation. Thus, the data for the volatile organic analytes (VOAs) are not directly comparable, because they span the timeframe of the SVE operation. Although the VOA data of different timeframes provide a basis for evaluating the changes in the VOA soil concentrations over time, the VOA data from the 1992 to 1993 timeframe were not included in the Phase II COPC data screening because the more recent data (2004 to 2006) were considered more representative data. The data from all of the 216-Z-9 boreholes were used for non-VOA COPCs.

Five boreholes within about 75 m (246 ft) of the 216-Z-1A with relevant soil data were evaluated for inclusion in the COPC screening process. Data from the four boreholes most representative of providing information on the extent of non-radionuclide contamination at the waste site were identified for Phase I COPC screening. Plutonium-239/240 (Pu-239/240) and americium-241 (Am-241) data are from the analytical results documented in RHO-ST-17, *Distribution of Plutonium and Americium Beneath the 216-Z-1A Crib: A Status Report*, which documents the work performed to characterize the distribution of plutonium and americium in sediments beneath the crib.

The borehole 299-W18-249 was excluded from the Phase I COPC screening for 216-Z-1A because it was located 50 meters from 216-Z-1A; however, this borehole is located directly adjacent to the 216-Z-18 waste site (Figure E2-5a) and was included in the Phase I COPC screening for 216-Z-18. Data from the 299-W18-252 borehole was included in the initial Phase I COPC screening and transect evaluation

(Section E4.3), but was not included in the Phase II data screening because its distance from the waste site was regarded as too great (>70 m [230 ft]), for the data to be considered representative for modeling of the 216-Z-1A Crib.

Data from only one borehole C4545 were available for COPC screening at 216-A-8. Sample data from borehole 216-W15-202 were used for evaluation of the 216-Z-8 French Drain (RHO-RE-EV-46 P).

E2.2 Phase I COPC Screen: Initial Screening of Maximum Values Using EPA SSL and Model Toxics Control Act Criteria

The initial COPC screening step has two parts: (1) the available sampling data and site information are reviewed to select data applicable to evaluate groundwater impacts and, (2) analyte concentrations within the data set are evaluated to identify analytes and affected environmental media (i.e., soil) that have the potential to affect groundwater requiring a more detailed assessment.

E2.2.1 Identify Soil Screening Levels for Protection of Groundwater

Screening levels are obtained from several different sources to evaluate the vadose zone soils for the protection of groundwater. The EPA methodology for developing SSLs to identify contaminants in soil that have the potential to adversely affect groundwater is described for chemicals in EPA/540/R-95/128, *Soil Screening Guidance: Technical Background Document*, and for radionuclides in EPA/540-R-00-006, *Soil Screening Guidance for Radionuclides: Technical Background Document*. Soil concentrations protective of groundwater are back calculated from an acceptable groundwater concentration (i.e., a maximum contaminant level [MCL; radionuclides or chemicals] or a risk-based groundwater concentration [chemicals]). First, the acceptable groundwater concentration is multiplied by a dilution attenuation factor (DAF) to arrive at an acceptable soil leachate concentration, and then linear equilibrium soil/water partitioning equations are used to calculate a soil concentration corresponding to the target leachate or groundwater concentration. The EPA equations include the following assumptions for the migration-to-groundwater calculations:

- The contamination source is infinite
- Contaminants are uniformly distributed throughout the zone of contamination
- Soil contamination extends from the contaminated zone to the water table
- There is no chemical or biological degradation in the unsaturated zone
- Soil/water partitioning in the contaminated zone is in equilibrium and is instantaneous and linear
- The receptor well is screened within the groundwater plume
- There is no dilution of contaminants in groundwater from upgradient recharge
- Aquifer properties are homogeneous and isotropic

The SSLs for chemicals are available at the *Regional Screening Levels for Chemical Contaminants at Superfund Sites* (EPA, 2009) screening level/ preliminary remediation goal website.

Additionally, the State of Washington within the *Washington Administrative Code* (WAC) 173-340-747 prescribes specific methods that may be used to evaluate the protection of groundwater pathway. Screening levels for the protection of groundwater are calculated using the fixed parameter three-phase partitioning model as described in WAC 173-340-747(3)(a). For purposes of this evaluation, the lower of the EPA SSL or the WAC 173-340-747(3)(a) was selected.

For radionuclides, EPA/540-R-00-006 provides generic soil screening levels. The soil screening levels for the migration to groundwater pathway were developed using a DAF of 20 to account for natural processes

that reduce contaminant concentrations in the subsurface. Table E2-2 contains soil background levels, EPA screening levels, and EPA soil-water partitioning coefficient (K_d) values. These values are used in the COPC selection process.

Table E2-2. Summary of Phase I Parameter Screening Values

Analyte Name	Values Used in Screening		
	Soil Background ($\mu\text{g/kg}$ or pCi/g)	Soil Screening Levels ($\mu\text{g/kg}$ or pCi/g)	EPA K_d Value (cm^3/g)
Radionuclides			
Americium-241	--	2.52	8.2
Carbon-14	--	40	0.8
Cesium-137	--	40.8	--
Europium-152	--	--	--
Europium-154	--	--	--
Europium-155	--	--	--
Gross alpha	--	--	--
Gross beta	--	--	--
Neptunium-237	--	0.09	0.1
Nickel-63	--	34.2	34
Plutonium-238	--	1.56	5
Plutonium-239/240	--	1.56	5
Potassium-40	16.6	--	--
Protactinium-231	--	--	--
Radium-226	0.815	0.32	3
Radium-228	--	0.32	3
Strontium-90	--	0.192	1
Technetium-99	--	3.73	0.007
Thorium-230	--	6.06	20
Total beta radiostrontium	--	0.192	--
Uranium-233	--	0.24 ^a	0.4
Uranium-234	1.1	0.24 ^a	0.4
Uranium-235	0.109	0.24 ^a	0.4
Uranium-236	--	0.24 ^a	0.4
Uranium-238	1.06	0.24 ^a	0.4
Metals			
Antimony	5,000	270	45
Arsenic	6,470	1.3	29
Barium	132,000	82,000	41
Beryllium	1,510	3,200	790

Table E2-2. Summary of Phase I Parameter Screening Values

Analyte Name	Values Used in Screening		
	Soil Background (µg/kg or pCi/g)	Soil Screening Levels (µg/kg or pCi/g)	EPA K _d Value (cm ³ /g)
Cadmium	1,000	380	75
Cobalt	15,700	490	45
Copper	22,000	46,000	35
Hexavalent chromium ^b	--	192	0
Iron	32,600,000	640,000	25
Lead	10,200	14,000	900
Manganese	512,000	57,000	65
Mercury	330	30	52
Nickel	19,100	48,000	65
Phosphorus	--	2.7	35
Selenium	--	260	5
Silver	730	1,600	8.3
Thallium	--	140	150,000
Vanadium	85,100	2,600	1,000
Semi-Volatile Organic Compounds			
Aroclor-1254	--	8.8	260
Aroclor-1248	--	5.2	150
Benzo(a)anthracene	--	10	350
Benzo(a)pyrene	--	3.5	1,200
Benzo(b)fluoranthene	--	35	1,200
Bis(2-ethylhexyl) phthalate	--	1,100	240
Naphthalene	--	0.47	3.1
Pentachlorophenol	--	5.7	9.9
Phenyl sulfone	--	71	2.2
Tributyl phosphate	--	36	4.7
Volatile Organic Compounds			
1,1,1-Trichloroethane	--	70	0.088
1,1,2,2-Tetrachloroethane	--	0.026	0.19
1,1,2-Trichloroethane	--	0.078	0.12
1,1-Dichloroethane	--	0.69	0.064
1,1-Dichloroethene	--	2.5	0.064
1-Butanol	--	760	0.0069
2-Butanone	--	1,500	0.0090
Acetic acid, methyl ester	--	7,500	0.0061

Table E2-2. Summary of Phase I Parameter Screening Values

Analyte Name	Values Used in Screening		
	Soil Background ($\mu\text{g}/\text{kg}$ or pCi/g)	Soil Screening Levels ($\mu\text{g}/\text{kg}$ or pCi/g)	EPA K_d Value (cm^3/g)
Acetonitrile	--	26	0.0093
Benzene	--	0.21	0.29
Bromodichloromethane	--	0.032	0.064
Bromoform	--	2.3	0.064
Bromomethane	--	2.2	0.026
Carbon tetrachloride	--	0.077	0.088
Chloroform	--	0.053	0.064
Chloromethane	--	49	0.026
cis-1,2-Dichloroethylene	--	21	0.079
Ethylbenzene	--	1.7	0.89
Hexachloroethane	--	2.9	0.39
Methylene chloride	--	1.2	0.043
Nitromethane	--	0.12	0.021
Tetrachloroethene	--	0.049	0.19
Toluene	--	690	0.47
trans-1,2-Dichloroethylene	--	29	0.079
Trichloroethene	--	0.72	0.12
Wet Chemistry Parameters			
Nitrate ^b	52,000	102,400	--
Nitrite	--	6,400	--
Phosphate	785	--	--
Sulfate	--	--	--

Notes:

Hexachloroethane and Naphthalene were analyzed using two analytical methods: EPA Method 8270 and EPA Method 8260.

DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*

DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*

EPA/540/R-96/018, *Soil Screening Guidance: User's Guide*, Publication 9355.4-23

EPA/540-R-00-007, *Soil Screening Guidance for Radionuclides: User's Guide*, OSWER 9355.4-16A

a. SSL calculated based on proposed MCL of 20 pCi/L (activity) for uranium.

b. WAC 173-340-747, "Model Toxics Control Act—Cleanup," "Deriving Soil Concentrations for Ground Water Protection."

-- = No value

E2.2.2 Initial COPC Selection Process

Typically, not all contaminants present at a site pose a threat to groundwater or contribute significantly to overall site risks. The EPA guidelines (EPA 540/1-89/002) recommend focusing on a group of COPCs

based on inherent toxicity, site concentration, and the behavior of the constituents in the environment. To identify these COPCs, groundwater protection screening levels (listed in Table E2-2) are compared to site concentrations of analytes in soil.

The steps of the selection process for identifying initial soil COPCs for the evaluation of groundwater protection are as follows.

1. **Identify Non-Detected Analytes:** Analytes that have been collected from appropriate locations, have adequate detection limits, and that have not been detected at least once in deep zone samples are eliminated as COPCs. All analytes detected at least once are carried forward to the next step of the process.
2. **Essential Nutrients:** Essential nutrients are those analytes considered essential for human nutrition and are not associated with toxicity to humans. Essential nutrients (calcium, magnesium, potassium, and sodium) were measured in soil and are not considered for inclusion as COPCs.
3. **Radiation with Half-Lives of Less than 3 Years:** Radioisotopes with half-lives less than or equal to 3 years are eliminated from further consideration because only a small fraction of activity remains after 30 years of decay. Antimony-125 and cesium-134 were measured in soil but were not detected and are not considered for inclusion as COPCs.
4. **Comparison of Maximum Detected Contaminant Concentrations to Soil Screening Levels:** The soil screening levels listed in Table E2-2 were used as the groundwater protection screening values. For nonradionuclides, the maximum detected concentrations in soil from each of the soil borings were compared to SSLs for migration to groundwater, and EPA's generic SSLs for migration to groundwater using a dilution attenuation factor of 20 were used for radionuclides (EPA/540-R-00-006). If contaminant concentrations were above screening values, they were carried forward into the next step of the process.
5. **Comparison of Maximum Detected Contaminant Concentrations to Background:** The maximum concentrations of inorganics and radionuclides were compared to the Hanford Site-specific 90th percentile background values shown in Table E2-2. Inorganics and radionuclides were eliminated as COPCs based on these background levels if their maximum concentrations did not exceed background.

E2.3 Phase II Screening Steps

Phase II of the COPC screening process for groundwater protection involved five main steps of evaluation. The approach for this phase of screening differed from that in Phase I, in that all data for all COPCs from all boreholes near each waste site were evaluated. The screening was limited to data for subsurface samples from depths above the water table, i.e., within the vadose zone. The following water table depths were used to define the depth threshold of vadose zone samples included in the screening: 216-A-8, 80 m (256.7 ft) bgs; 216-Z-1A and 216-Z-18, 73.5 m (235.8 ft) bgs; 216-Z-9 is 59 m (221 ft) bgs.

As in other screening analyses, fewer data were evaluated in the successive steps of the process as data were screened out according to the criteria associated with each screening step. The criteria and evaluation process associated with each of the five main steps in the Phase II COPC evaluation process are described in Sections E2.2.1 to E2.2.5. A summary of the values used for these screening criteria in the Phase II COPC data screening are summarized in Table E2-3.

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Soil Background ^a	Values Used in Screening				K _d Reference
		EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	mg/kg	K _d Value for Groundwater Arrival Time Screen	mL/g	
Metals and Other Inorganics			mg/kg	mg/kg	mL/g	
Aluminum	11,800	1500		1,500		ORNL, 2009; EPA, 2009
Antimony ^b	5.2	5.42		45		Ecology, 2009
Arsenic	6.47	0.0341		29		Ecology, 2009
Barium	132	1648		25		Hanford Site-specific K _d value: PNL-7660
Beryllium	1.51	63		790		Ecology, 2009
Cadmium ^c	0.93	0.69		30		Harford Site-specific K _d value: PNL-7660
Hexavalent chromium ^d	--	0.192		0		Harford Site-specific K _d value: PNL-7660
Cobalt	15.8	4.35		50		Ecology, 2009
Copper	21.6	284		22		Ecology, 2009
Iron	33,050	152		25		EPA, 2009; ORNL, 2009
Lead	10.3	3000		30		Harford Site-specific K _d value: PNL-7660
Manganese	506	65.3		50		Harford Site-specific K _d value: PNL-7660
Mercury	0.35	2.09		30		Harford Site-specific K _d value: PNL-7660
Nickel	19.1	130		65		Harford Site-specific K _d value: PNL-7660
Selenium ^e	0.78	5.2		5		Ecology, 2009
Silver	1.38	13.6		8.3		Ecology, 2009
Thallium ^f	3.7	1.48		71		Ecology, 2009
Vanadium	85	2240		1,000		Ecology, 2009
Nitrogen in nitrate and nitrite ^g	12.2	40		0		Harford Site-specific K _d value: PNNL-13895
Phosphate	0.668	0.00064		0		Ecology, 2009
Sulfate	264	1030		0.00612		ORNL, 2009

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Soil Background ^a	Values Used in Screening				K_d Reference
		EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K_d Value for Groundwater Arrival Time Screen	K_d Value for COC Modeling	mL/g	
Organic Compounds	mg/kg	mg/kg	mL/g	mL/g		
Acetonitrile						ORNL, 2009
Aroclor-1248		0.0386	43.9			EPA, 2009; ORNL, 2009 (Using $K_d = K_{oc}/1000$)
Aroclor-1254		0.0663	75.6			EPA, 2009; ORNL, 2009 (Using $K_d = K_{oc}/1000$)
Acetic acid, methyl ester		32.6	0.0033			EPA, 2009; ORNL, 2009 (Using $K_d = K_{oc}/1000$)
Benzene		0.00448	0.062	0.05		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Benzo(a)anthracene		0.856	360			Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Benzo(a) pyrene		0.232	970			Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Benzo(b)fluoranthene		2.95	1230			Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Bis(2-ethylhexyl) phthalate		13.4	111.1			Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Bromodichloromethane		0.00368	0.055	0.05		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Bromoform		0.0363	0.126	0.1		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Bromomethane		0.0518	0.009			Ecology, 2009 (Using $K_d = K_{oc}/1000$)
1-Butanol		3.31	0.0069	0.01		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
2-Butanone		21.8	0.027			ORNL, 2009
Carbon tetrachloride		0.0315 ^b	0.152	0.15		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Chloroform		0.00751	0.053	0.05		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Chloromethane						
1,2-Dibromo-3-chloropropane		0.000362	0.13			ORNL, 2009
1,1-Dichloroethane		0.0419	0.053	0.05		Ecology, 2009 (Using $K_d = K_{oc}/1000$)

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Soil Background ^a	Values Used in Screening			K_d Reference
		EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K_d Value for Groundwater Arrival Time Screen	K_d Value for COC Modeling	
1,1-Dichloroethene		0.0501	0.065		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
cis-1,2-dichloroethylene		0.350	0.0355		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
trans-1,2-dichloroethylene		0.543	0.038		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Ethylbenzene		0.0344	0.204	0.2	Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Hexachloroethane		0.125	1.78		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Methylene Chloride		0.0218	0.01	0.01	Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Naphthalene		10.2	1.19		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Nitromethane		0.0116	0.592	0.6	Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Pentachlorophenol					
Phenyl sulfone		0.00123	0.079	0.05	Ecology, 2009 (Using $K_d = K_{oc}/1000$)
1,1,2,2-Tetrachloroethane		0.000859	0.265	0.25	Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Tetrachloroethylene		4.65	0.14		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Toluene		0.398	43.9		ORNL, 2009 (Using $K_d = K_{oc}/1000$)
Tributyl phosphate		1.584	0.14		Ecology, 2009 (Using $K_d = K_{oc}/1000$)
1,1,1-Trichloroethane		0.004	0.075	0.05	Ecology, 2009 (Using $K_d = K_{oc}/1000$)
1,1,2-Trichloroethane		0.0223	0.094	0.1	Ecology, 2009 (Using $K_d = K_{oc}/1000$)
Trichloroethylene					

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Soil Background ^a	Values Used in Screening				K_d Reference
		Radionuclides	pCi/g	EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K_d Value for Groundwater Arrival Time Screen	
					mL/g	mL/g
Americium-241				200		Hanford Site-specific K_d value: PNL-7660
Carbon-14		8.0		0	0	Hanford Site-specific K_d value: PNNL-13895; RPP-13310
Cesium-137 + Daughters				25		Hanford Site-specific K_d value: PNNL-13895; RPP-13310
Europium-152				200		Hanford Site-specific K_d value: PNL-7660
Gadolinium-152 ⁱ				240		EDF-ER-275
Europium-154				200		Hanford Site-specific K_d value: PNL-7660
Europium-155				200		Hanford Site-specific K_d value: PNL-7660
Neptunium-237				15		Hanford Site-specific K_d value: PNL-11800
Nickel-63				30		Hanford Site-specific K_d value: PNL-7660
Plutonium-238				200		Hanford Site-specific K_d value: PNL-7297
Plutonium-239/240				200		Hanford Site-specific K_d value: PNL-7660
Potassium-40		16.6		5.5		Hanford Site-specific K_d value: PNL-11800
Protactinium-231				550		EDF-ER-275
Radium-226	0.815		0.036	3		ORNL, 2009
Radium-228			0.012	3		ORNL, 2009
Strontium-90				25		Hanford Site-specific K_d value: PNL-7660
Total beta radiostrontium					25	Hanford Site-specific K_d value: PNL-7660
Gross beta					22.96	

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Soil Background ^a	Values Used in Screening			
		EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K _d Value for Groundwater Arrival Time Screen	K _d Value for COC Modeling	K _d Reference
Technetium-99		3.6		0	Hanford Site-specific K _d value; PNL-7297
Thorium-230			200		Hanford Site-specific K _d value; EPA/520/6-78-007A
Thorium-232	1.32		200		Hanford Site-specific K _d value; EPA/520/6-78-007A
Uranium	3.21				
Uranium-234	1.098				
Uranium-235	0.109				
Uranium-236					
Uranium-238	1.059				

Notes:

 Values used in Step 2 of the Phase II screening process and are the larger of the soil background and the EPA Soil-Water Partitioning values.

 Values used in Step 5 of the Phase II screening process (groundwater arrival time and/or fate and transport modeling activities).

- a. 90th percentile soil background values for non-radionuclides from DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*, except where noted.
- b. Antimony background = 90th percentile of Statewide soil background data (Ecology Publication 94-115, *Natural Background Soil Metals Concentrations in Washington State*, p. 11-134).
- c. Cadmium background = 90th percentile of State soil background data for the Yakima Basin (Ecology Publication 94-115, p. 11-42).
- d. A K_d value of zero was used in the calculation of the Chromium VI screening value from the EPA Soil-Water partition equation, rather than the K_d value of 19 listed in the Ecology CLARC Table (Ecology, 2009).
- e. Selenium background = 90th percentile of Statewide soil background data (Ecology Publication 94-115, p. 11-135).
- f. All Thallium background analyses reported in DOE/RL-92-24 and Ecology Publication 94-115 were below detection limits. The background screening level was, therefore, based on the limit of detection (LOD) of 3.7 mg/Kg reported in DOE/RL-92-24, which is lower than the detection limit of value 5 mg/Kg for Thallium reported by Ecology Publication 94-115.
- g. Values are for nitrate and nitrite re-calculated as Nitrogen; i.e., Nitrogen in nitrate+nitrate.
- h. Carbon tetrachloride screening value calculated from the EPA Soil-Water partition equation used a groundwater protection level of 3.4 µg/L, per

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

		Values Used in Screening			
Groundwater Protection COPC	Soil Background ^a	EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K _d Value for Groundwater Arrival Time Screen	K _d Value for COC Modeling	K _d Reference
EPA et al., 2008, <i>Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington.</i>					
i. Gadolinium-152 is listed because it is a long-lived decay product of the parent isotope, Europium-152, which is a COPC, and a half-life of 13.5 years.					
EPA, 2009, Cleanup Levels and Risk Calculations (CLARC) database					
EDF-ER-275, <i>Fate and Transport Modeling Results and Summary Report</i>					
EPA, 2009, "Regional Screening Levels for Chemical Contaminants at Superfund Sites"					
EPA/520/6-78-007A, <i>Radionuclide Interactions with Soil and Rock Media, Volume I: Processes Influencing Radionuclide Mobility and Retention, Element Chemistry and Geochemistry, Conclusions and Evaluation</i>					
ORNL, 2009, Risk Assessment Information System					
PNL-7297, <i>Hanford Waste-Form Release and Sediment Interaction: A Status Report with Rationale and Recommendations for Additional Studies</i>					
PNL-7860, <i>Compilation of Data to Estimate Groundwater Migration Potential for Constituents in Active Liquid Discharges at the Hanford Site</i>					
PNNL-11800, <i>Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site</i>					
PNNL-13895, <i>Hanford Contaminant Distribution Coefficient Database and Users Guide</i>					
RPP-13310, <i>Modeling Data Package for an Initial Assessment of Closure for C Tank Farm</i>					
COC = contaminant of concern					
Eq. = equation					
K _{oc} = soil organic carbon water partition coefficient					

The soil concentration data for the 200-PW-1, 200-PW-3, and 200-PW-6 waste site boreholes reported in units of $\mu\text{g}/\text{kg}$ in the RIFAT and RISAT data reports (ECF-200PW136-10-0337) were converted to units of mg/kg for comparison to soil background and WAC 173-340, “Model Toxics Control Act – Cleanup,” EPA SSLs, and EPA Soil Water Partition equation values. Data reported for a COPC by multiple analytical methods for the same sample (depth), the data sets were combined where there were not multiple data values reported for a sample (depth); i.e., only one value reported overall for the combined data set. Where there were multiple values reported by different methods for a single sample, the largest values were used to represent the sample.

Data for nitrate, nitrite, and total nitrogen in nitrate and nitrite were reported separately in units of $\mu\text{g}/\text{kg}$ in the RIFAT data reports, which were also converted to units of mg/kg . The total nitrogen for the nitrate and nitrite data values of each sample were then calculated from the mass fraction (ratio) of nitrogen in nitrate (fraction of nitrogen in nitrate [by weight] = 0.226¹), nitrogen and nitrite (fraction of nitrogen in nitrite [by weight] = 0.304²) for comparison to the total nitrogen data and also because the groundwater protection metrics are typically in units of nitrogen in nitrate+nitrite. The nitrogen values for nitrate and nitrite were then added, and compared to the values reported for total nitrogen, where they were also reported. Where there was more than one value for total nitrogen in nitrate+nitrite per sample, the larger values was used to represent the sample.

E2.3.1 Step 1: Data Screen by Lab Code

The first step in this phase of the evaluation was to screen all data records by lab code, screening out all “non-detect” data having a “U” lab code, and to flag data with other lab codes (e.g., “J,” “E,” “B,” and “C” codes)³ that denote data that may be questionable (estimated data, lab contamination, etc.), or that otherwise indicate data concerns in terms of detection and/or whether the data are sufficiently quantifiable for risk characterization applications. Samples with “B” codes, denoting analyte contamination in the laboratory “blank” were also omitted from the screening as unrepresentative of soil contamination.

E2.3.2 Step 2: Data Screen Using Background and the Soil-Water Partition Equation

All non-radionuclide COPC data above detection were then screened against soil background and/or the soil concentration levels based on the EPA Soil-Water Partition Equation for Migration to Groundwater Pathway (EPA/540/R-95/128, Equation 22, Section 2.5.1) using the parameter values identified in WAC 173-340-747 for the Fixed Parameter three-phase partitioning equation (WAC-173-340-747, Equation 747-1). Screening using the EPA Soil-Water Partition Equation and/or Equation 747-1 is a conservative screen involving the determination of soil (source term) concentrations that are below groundwater protection levels (e.g., MCLs) assuming, e.g., no vadose zone, and an infinite source, as described in Section E2.1.2.

Detected COPC data were also compared to the 90th percentile soil background values for naturally occurring non-radioactive analytes (e.g., DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*) and for naturally-occurring radionuclides in the Hanford Site vadose zone (DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*) to determine which of the data could be regarded as belonging to the population of naturally occurring soil background values. All data less than the 90th percentile values of the background population were screened out as indistinguishable from background, and were, therefore, considered to posing no additional risk above background levels.

¹ Fraction of nitrogen in nitrate = MW of N / MW of NO³⁻ that = (14g/mol) / (62 g/mol) = 0.226.

² Fraction of nitrogen in nitrite = MW of N / MW of NO²⁻ that = (14g/mol) / (46 g/mol) = 0.304.

³ Laboratory Qualifier Codes are defined in Section 3.2.8 of CP-15383, *Common Requirements of the Format for Electronic Analytical Data (FEAD)*.

E2.3.3 Step 3: Quantitation Considerations

The COPC data that passed the previous steps of the Phase II screening were then evaluated in Step 3 against criteria relevant to whether the remaining data are credibly quantifiably above detection.

The PQL screening in Step 3 involved the determination as to whether the data above detection limits are credibly/reasonably quantifiable for the intended use (risk-based screening and evaluation).

WAC 173-340, “Model Toxics Control Act – Cleanup,” defines PQLs as:

...the lowest concentration that can be reliably measured within specified limits of precision, accuracy, representativeness, completeness, and comparability during routine laboratory operating conditions, using department approved methods.

Data above detection limits, may or may not be quantifiable for purpose of the application, and/or may be identified as “estimated” as indicated by the laboratory code. The issue of defining and utilizing PQLs and/or other quantitation limits is addressed in both state and federal guidelines, as well as in the technical literature as follows:

- Currie, 1968, “Limits for Qualitative Detection and Quantitative Determination: Application to Radiochemistry”
- Ecology, 1993, “Guidance for the Use of Tables: Practical Quantitation Limits (PQLs), Method Detection Limits (MDLs), and PQL Comparisons to Method B Cleanup Levels”
- EPA 540-R-01-003, *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites*
- EPA, 2006, MDL Factsheet, “IDL-MDL-PQL: What the ‘L’ is going on? What does all this alphabet soup really mean?”
- WAC 173-340-700, “Overview of Cleanup Standards”
- WAC 173-340-709, “Methods for Defining Background Concentrations”

Most technical definitions of PQL are based on parameters such as the method detection limit (MDL) for non-radionuclides MDL, the method detection activity (MDA) for non-radionuclides, and/or associated or the standard deviations.

Non-radionuclide data was not subjected to PQL screening due to the absence information on the MDL, particularly for much of the older legacy data, and also because the contract-required detection limit information alone was deemed inadequate for PQL screening. However, a decision rule for PQL screening of radionuclide data was adopted by establishing a PQL threshold of three times the MDA value associated with the radionuclide measurements, i.e., data values \leq three times the MDA were considered as not sufficiently quantifiable to carry forward as COPC data.

E2.3.4 Step 4: Pathway and Anomalous Data Evaluation

Step 4 of COPC evaluation involved the evaluation of pathway criteria and anomalous data. The pathway aspect of Step 4 in the screening evaluation involves the elimination of groundwater protection COPCs that are not regulated, not subject to the ingestion pathway, or which have no quantifiable or appropriate basis for evaluation as groundwater protection COPCs (e.g., no groundwater protectiveness metric).

The evaluation of anomalous data involved further scrutiny of data in instances where a COPC appeared to be unusual or anomalous. In some cases, this phase of the evaluation involved the re-evaluation of

sampling and analysis records and QA/QC reports. The identification of data regarded as anomalous were based on criteria that included the following:

- Anomalous concentrations (e.g., singular concentration anomalies)
- Spatial occurrences (e.g., depth) inconsistent with the conceptual model
- Anomalous patterns and/or correlations in COPC behavior

This phase of the COPC evaluation was performed primarily to ensure that COPC data passing the previous screening phases were not artifacts of e.g., transcription errors, laboratory contamination, borehole contamination, or other reasons, before including the data in the fate and transport modeling evaluation.

E2.3.5 Step 5: Groundwater Arrival Time and Half-Life Screen

The remaining COPCs were then evaluated in the context of their ability to affect groundwater within a specified timeframe based on a 1,000-year timeframe of compliance. The timeframe for compliance regarding the assessment of protectiveness for groundwater is related to the CERCLA consideration of long-term effectiveness in the analysis and performance of remedial actions (40 CFR 300.430), and regulations and guidelines regarding the assessment of controls for radiological and hazardous constituents. The basis for a compliance timeframe of at least 1,000 years is primarily derived from DOE Order 435.1, *Radioactive Waste Management*, concerning the performance objectives and performance assessment for low-level waste disposal, and EPA regulations concerning the effectiveness of controls for residual radioactive materials from inactive uranium processing sites (40 CFR 192.02, “Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings,” “Standards”; DOE/RL-2007-35, *200-UW-1 Operable Unit Remedial Action Goals for Removal/Treatment/Disposal Waste Sites*, Section 4.3).

This step in the Phase II screening process involved the elimination of COPCs that have no impact on groundwater within a 1,000-year compliance timeframe, and radionuclides with half-lives causing them effectively to decay to stable non-hazardous species before reaching groundwater. In this phase of the COPC evaluation, the maximum vadose zone depth of the data passing the previous screening phases was determined for each COPC at each waste site.

E2.3.5.1 Groundwater Arrival Time Screen

The time required for any non-zero impact to groundwater from COPC source terms at the maximum depth of occurrence in the vadose zone were compared to a 1,000-year timeframe of compliance for each COPC at each waste site. This temporal screening was based on vadose zone travel time results of transport modeling described in ECF-200PW1/3/6-10-0326, *200-PW-1/3/6 Screening Process and Contaminant Fate and Transport Model to Evaluate Impacts to Groundwater in Support of DOE/RL-2007-27 Draft B*, in a manner consistent with the EPA Soil Screening Guidance (EPA/540/R-95/128), using the COPC K_d values listed in Table E2-3. This step in the screening process is effectively a K_d screen owing to the systematic (essentially linear) relationships between source term depth, K_d , and travel time to groundwater as shown in Figure E2-6, based on the information described in ECF-200PW1/3/6-10-0326, Tables 15-17. The decision rule for this phase of screening was to screen out any COPC with K_d values that did not affect groundwater within the 1,000-year compliance timeframe, i.e., that yielded no calculated groundwater concentration greater than zero, at the maximum depth of occurrence.

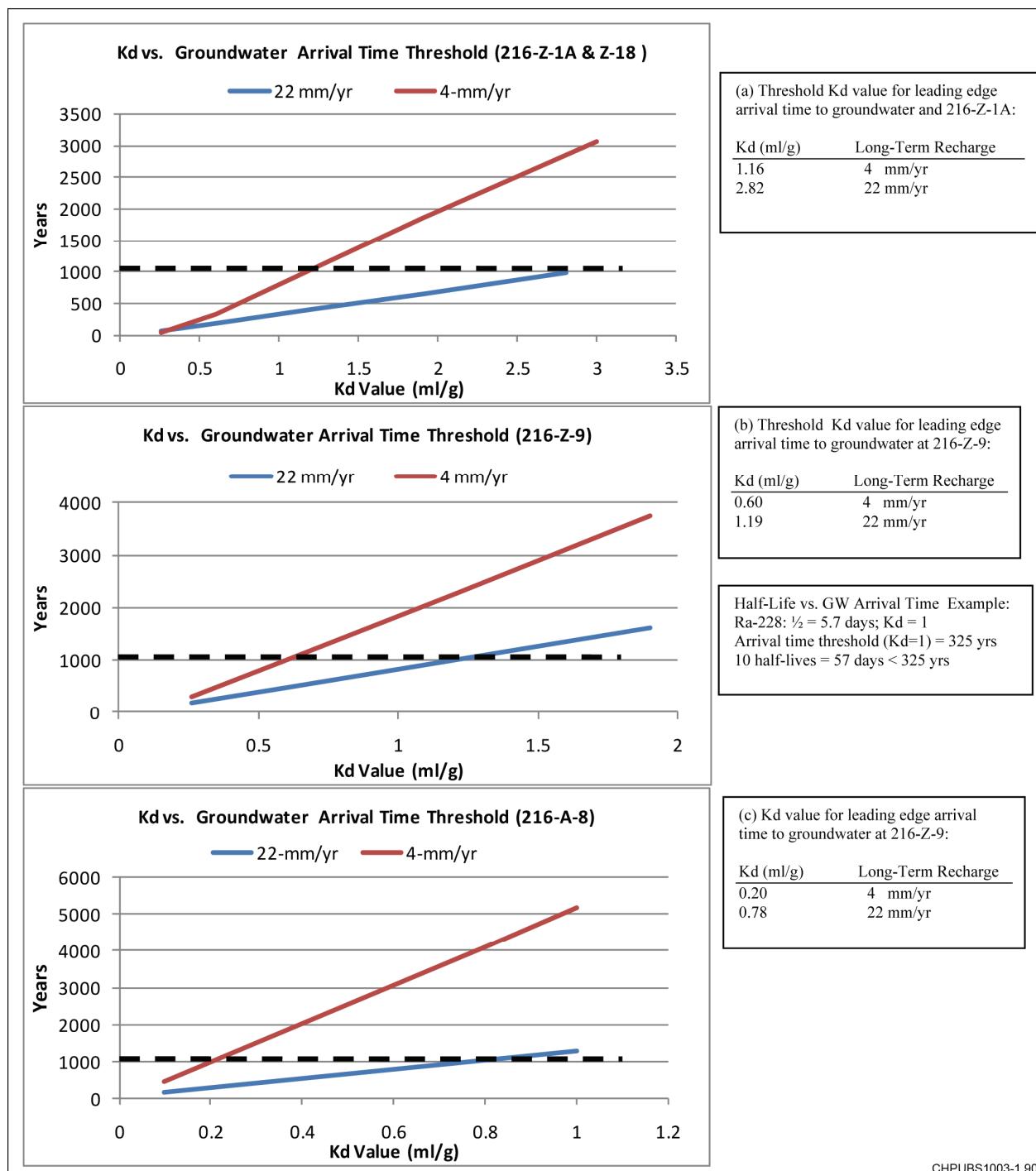


Figure E2-6. Groundwater Arrival Time as a Function of COPC K_d Values for (a) the 216-Z-1A and 216-Z-18 Cribs, (b) the 216-Z-9 Crib, and (c) the 216-A-8 Crib, Including an Example Calculation for the Comparison of the Travel Time to Groundwater to the Half-Life of Radium-228

CHPUBS1003-1.90

K_d threshold values as a function of the first non-zero concentration impact to groundwater were determined for long-term recharge rate of both 4 mm/yr and a 22 mm/yr (ECF-200PW1/3/6-10-0326). The K_d threshold values based on the larger recharge rate of 22 mm/yr were used in the Step 5 screen for conservatism in this step of the Phase II screening process. It is noted that the decision rule threshold is based on any non-zero impact to groundwater. This is significant in the context of uncertainty and conservatism, because this threshold represent the first indication of a groundwater impact, i.e., leading edge of a groundwater impact arrival time curve, rather than, e.g., peak concentrations, which arrive later than the leading edge. It is also noted that the groundwater arrival time screening criteria were applied regardless of subsequent peak concentrations, and only focused on whether there was any non-zero impact to groundwater within the timeframe of compliance.

The maximum depth of occurrence for each COPC passing the first three phases of screening and evaluation was used as the source term reference depth for most of the groundwater arrival time screening. For most COPCs in the Z-Area waste sites, the maximum depth of contamination was in, or above, the Cold Creek unit. The groundwater arrival time screen was, therefore, primarily based on a source term depth corresponding to the deepest part (i.e., bottom) of the Cold Creek unit as described in ECF-200PW1/3/6-10-0326 and Table E4-1. Thus, the use of a reference depth for most of the groundwater arrival time screening that is \geq to the maximum depth of screened COPC data was adequate because contamination at shallower depths would have longer groundwater arrival times than that for the reference conditions. Figures E2-7 and E2-8 illustrate the contaminant depths used for most of the groundwater arrival time screening.

The lowest COPC K_d values yielding no impact on groundwater within the 1,000 year timeframe for sources at the depth of lower Cold Creek unit, and a recharge rate of 22 mm/yr was determined to be 2.8 mL/g for the 216-Z-1A and 216-Z-18 Cribs, 1.19 mL/g for the 216-Z-9 Crib, and a K_d value of 0.52 for the 216-A-8 Crib (see ECF-200PW1/3/6-10-0326, Section 5 for details). Thus, any COPC with larger K_d values were also screened out because larger K_d values result in longer travel time to groundwater. The groundwater arrival time was also determined for individual instances on a case-by-case basis where some screened COPC data occur below the reference depth at the bottom of the Cold Creek unit in the Z-Area waste sites in 200-West Area.

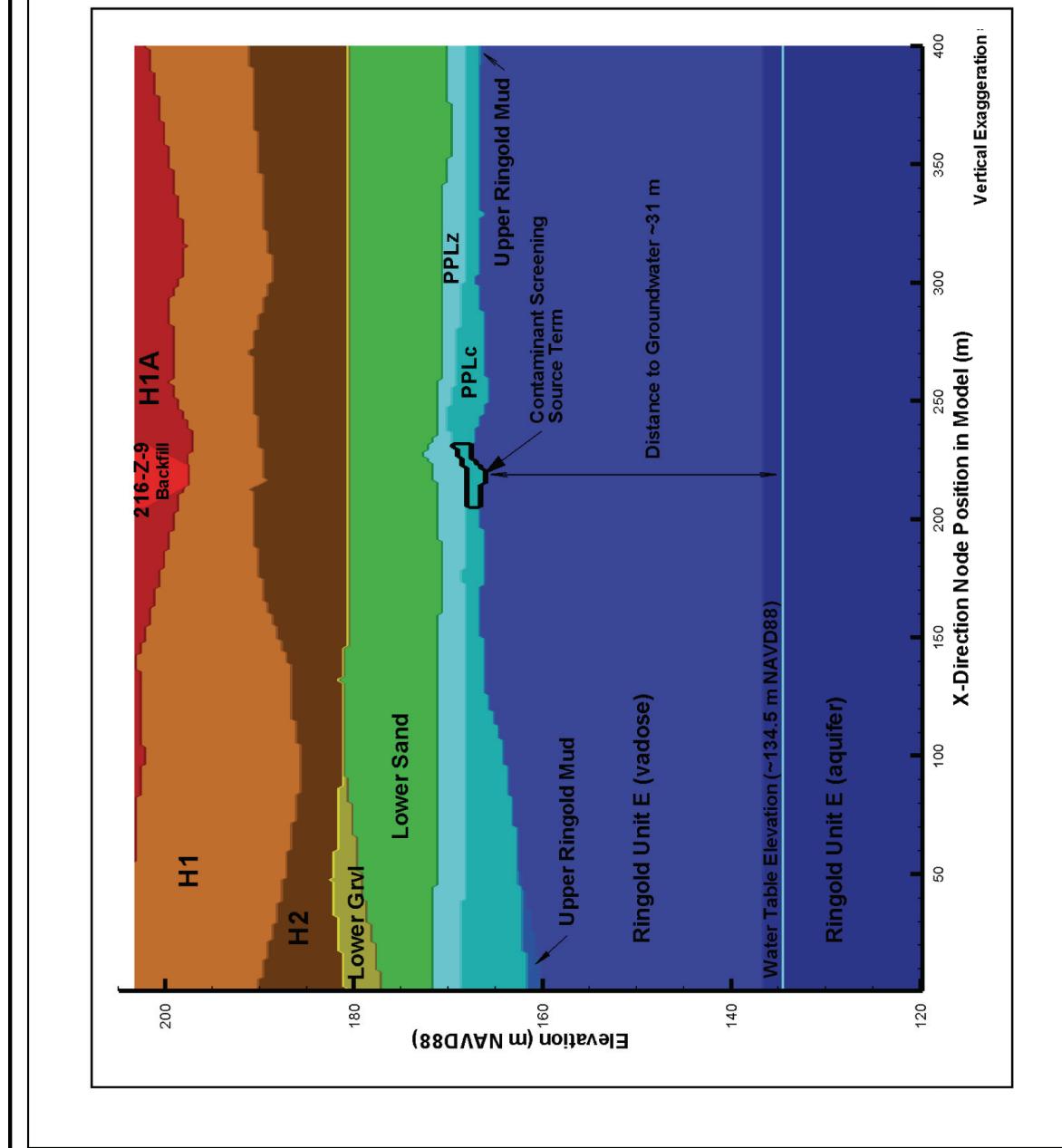
E2.3.5.2 Half-Life Screen

A half-live screen was applied to the remaining radionuclide COPCs and daughters, following the groundwater arrival time screen. The decision logic for the half-life screen was to eliminate radionuclide COPCs passing the groundwater arrival time screen, which would require ≥ 10 half-lives to reach groundwater. This decision criterion is based on the rationale that 99.9 percent of the radionuclide activity decays away for radionuclides requiring ≥ 10 half-lives to reach groundwater,⁴ and that ≤ 0.1 percent of the remaining activity does not pose a threat to groundwater. In practice, radionuclides with the non-zero groundwater impact arrival times greater than 1,000 years were screened out if 10 times the half-life of the parent and/or daughters were less than the time required for the first non-zero impact on groundwater concentration.

⁴ The fraction of radionuclide activity remaining after 10 half-lives is determined from the relationship between the number of half-lives (n), and the fraction of activity remaining (y), where: $y = 1/(2^n)$.

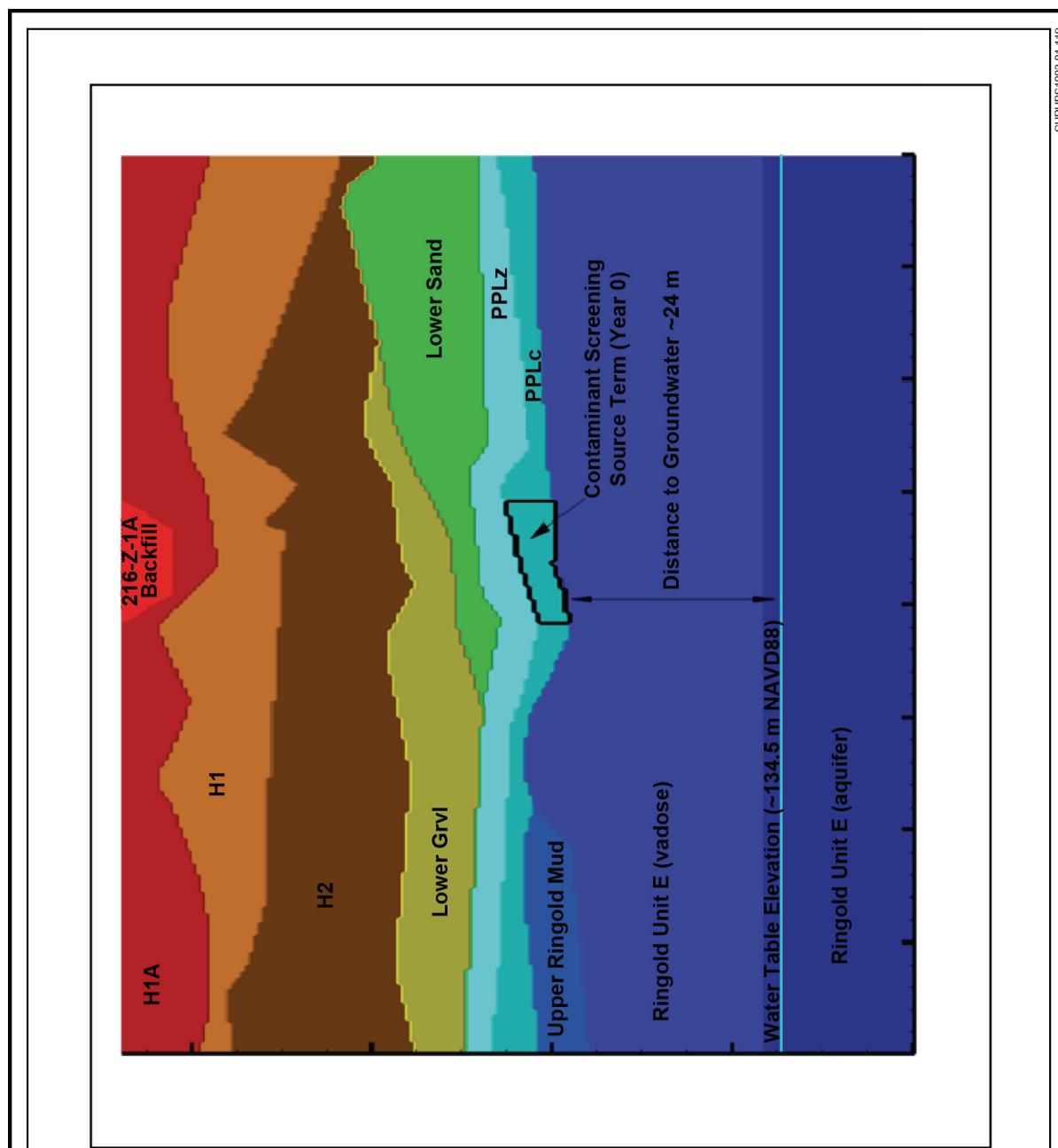
E2.4 Screened COPCs

The data for the COPCs passing all five steps of screening were then evaluated for impacts to groundwater using calculated source term concentrations for each COPC in the vadose zone fate and transport modeling. Chapter E4.0 describes the process used in the determination of the COPC source term concentrations. Chapter E5.0 describes the fate and transport modeling, parameterization of the model, assumptions, and uncertainties.



Note: The source term is shown as the outlined region at the base of the Cold Creek unit.

Figure E2-7. Geometry and Depth of the Reference Source Term Used for Groundwater Arrival Time Screening Analysis for Contaminants with K_d Values Greater than Zero at the 216-Z-9 and 216-Z-1A Cribs



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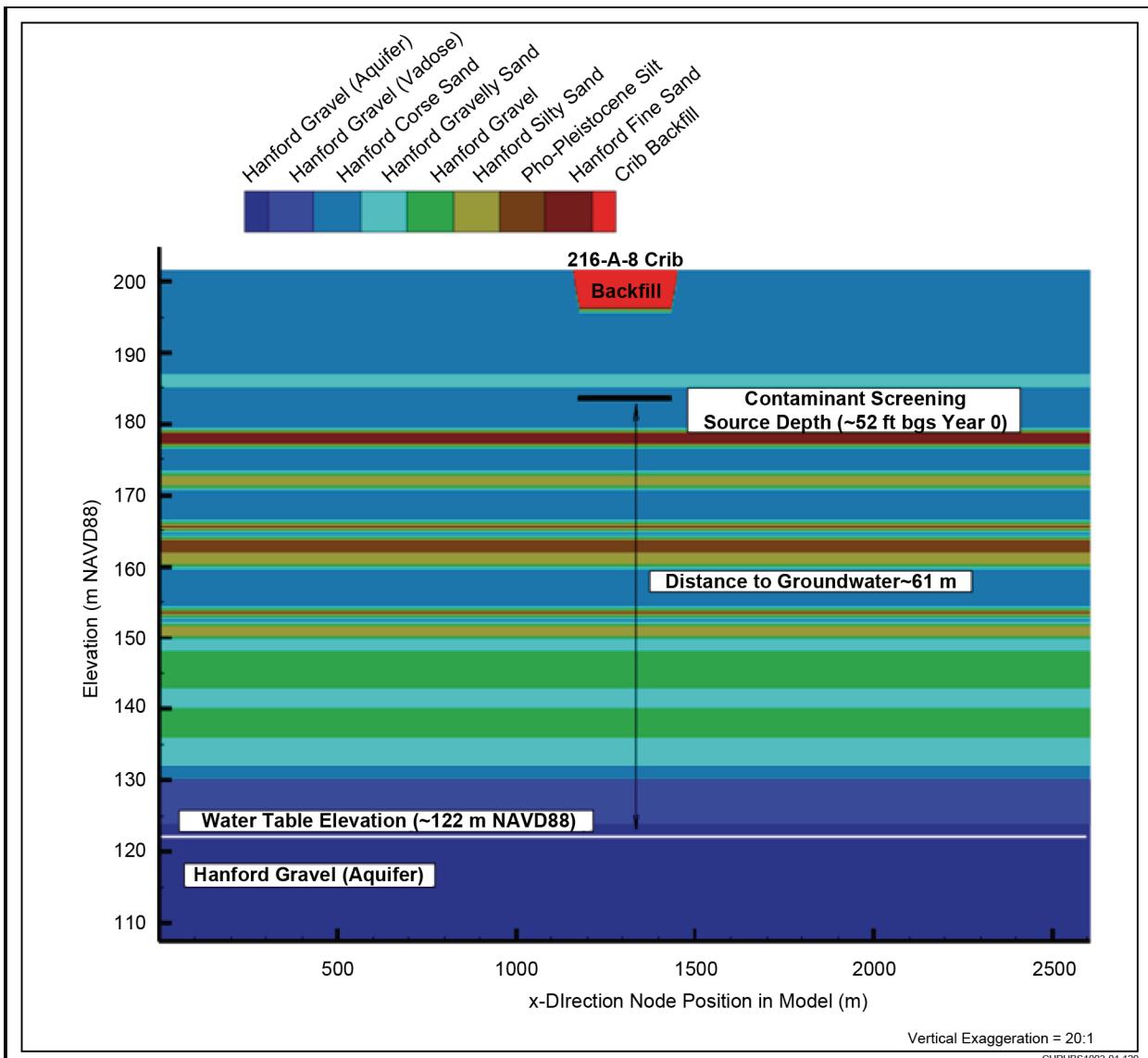


Figure E2-8. Depth of the Reference Source Term Used for Groundwater Arrival Time Screening Analysis for Contaminants with K_d Values Greater than Zero at the 216-A-8 Crib

E3.0 Results of COPC Screening Evaluation

The results of the Phase I and Phase II COPC screening and evaluation for groundwater protection are summarized in this Chapter for each of the waste sites evaluated (Table E3-1). The results of each phase of screening, and of each of the successive steps in the Phase II screening process is also summarized in Sections E3.1 and E3.2, respectively.

Only five of the seven waste sites identified in Table E2-1 had vadose zone soils containing groundwater protection COPCs. No COPCs for the protection of groundwater were identified from two sites, the 216-Z-361 Settling Tank and the 216-Z-10 Injection/Reverse Well. The results of the successive phases of the COPC screening and evaluation process are summarized in the following sections.

Table E3-1. Summary of the Results of the Phase I and Phase II COPC Screening Evaluation

Waste Site	Number of COPCs Passing Phase I Screen	Number of COPCs Passing Phase II Screen	COPCs Passing Phase II Screen for Fate and Transport Modeling
216-A-8	17	4	Hexavalent chromium, carbon-14, technetium-99, nitrogen in nitrate+nitrite
216-Z-8	3	0	None
216-Z-1A	14	7	1,1-Dichloroethane, carbon tetrachloride, chloroform, methylene chloride, tetrachloroethene, trichloroethylene, nitrogen in nitrate+nitrite
216-Z-18	19	7	Benzene, carbon tetrachloride, chloroform, ethylbenzene, methylene chloride, tetrachloroethene, nitrogen in nitrate+nitrite
216-Z-9	72*	15	Hexavalent chromium, nitrogen in nitrate+nitrite, 1-butanol, carbon tetrachloride, chloroform, methylene chloride, tetrachloroethene, trichloroethylene, 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, bromodichloromethane, bromoform, pentachlorophenol, technetium-99, uranium

* This number of COPCs from the Phase I screen is less than that reported in ECF-200PW1/3/6-10-0360 because nitrate and nitrite were combined with nitrogen in nitrate+nitrite for the Phase II screen.

E3.1 Results of the Phase I COPC Screen

The purpose of the initial phase of the COPC screening and evaluation process was to identify the COPCs for each waste site that warranted screening of all data points.

Table E3-1 lists the results of the Phase I COPC selection process for each of the waste sites included the 200-PW-1/3/6 OU. A detailed description of the initial COPC selection process including the rationale for selection or elimination of COPCs is described in a separate environmental calculation (ECF-200PW1/3/6-10-0360). Table E3-2 summarizes the results of the screening process, identifying the COPCs for each waste site.

Table E3-2. Contaminants of Potential Concern for Migration to Groundwater—Summary of the Results of the Phase I Screen of the 200-PW-1/3/6 COPC Screening Process for Groundwater Protection

Initial COPCs	Representative Sites				
	216-Z-1A Tile Field	216-Z-8 French Drain	216-Z-9 Trench	216-A-8 Crib	216-Z-18 Crib
Radionuclides					
Americium-241	✓*	✓	✓		
Carbon-14				✓	
Cesium-137				✓	
Europium-152			✓		
Europium-154			✓		
Europium-155		✓	✓	✓	
Gross alpha		✓	✓	✓	
Gross beta		✓	✓	✓	
Neptunium-237		✓	✓	✓	
Nickel-63			✓		
Plutonium-238		✓	✓		
Plutonium-239/240	✓*	✓	✓	✓	
Potassium-40			✓	✓	
Protactinium-231			✓		
Radium-226			✓		
Radium-228		✓		✓	
Strontium-90			✓		
Technetium-99			✓	✓	
Thorium-230			✓		
Total beta radiostrontium			✓	✓	
Uranium-233			✓		
Uranium-234			✓		
Uranium-235			✓		
Uranium-236			✓		
Uranium-238			✓		
Metals					
Antimony			✓		✓
Arsenic			✓		
Barium	✓		✓		✓
Beryllium					✓

Table E3-2. Contaminants of Potential Concern for Migration to Groundwater—Summary of the Results of the Phase I Screen of the 200-PW-1/3/6 COPC Screening Process for Groundwater Protection

Initial COPCs	Representative Sites				
	216-Z-1A Tile Field	216-Z-8 French Drain	216-Z-9 Trench	216-A-8 Crib	216-Z-18 Crib
Cadmium		✓			
Cobalt		✓			✓
Copper		✓			
Hexavalent chromium		✓		✓	
Iron		✓			✓
Lead		✓			
Manganese	✓		✓		✓
Mercury		✓			
Nickel		✓			✓
Selenium		✓		✓	
Silver		✓			
Thallium				✓	
Vanadium			✓		✓
Semi-Volatile Organic Compounds					
Aroclor-1254				✓	
Aroclor-1248		✓			
Benzo(a)anthracene		✓			
Benzo(a)pyrene		✓			
Benzo(b)fluoranthene		✓			
Bis(2-ethylhexyl) phthalate		✓			
Naphthalene		✓			
Pentachlorophenol		✓			
Phenyl sulfone		✓			
Tributyl phosphate		✓			
Volatile Organic Compounds					
1,1,1-Trichloroethane					✓
1,1,2,2-Tetrachloroethane			✓		
1,1,2-Trichloroethane			✓		
1,1-Dichloroethane	✓		✓		
1,1-Dichloroethene			✓		
1-Butanol			✓		

Table E3-2. Contaminants of Potential Concern for Migration to Groundwater—Summary of the Results of the Phase I Screen of the 200-PW-1/3/6 COPC Screening Process for Groundwater Protection

Initial COPCs	Representative Sites				
	216-Z-1A Tile Field	216-Z-8 French Drain	216-Z-9 Trench	216-A-8 Crib	216-Z-18 Crib
2-Butanone			✓		
Acetic acid, methyl ester			✓		
Acetonitrile			✓		
Benzene			✓		✓
Bromodichloromethane			✓		
Bromoform			✓		
Bromomethane			✓		
Carbon tetrachloride	✓		✓		✓
Chloroform	✓		✓		✓
Chloromethane			✓		
cis-1,2-Dichloroethylene	✓				
Ethylbenzene			✓		✓
Hexachloroethane			✓		
Methylene chloride	✓		✓		✓
Nitromethane			✓		
Tetrachloroethylene	✓		✓		✓
Toluene			✓		✓
trans-1,2-Dichloroethylene	✓				
Trichloroethene	✓		✓		✓
Wet Chemistry Parameters					
Nitrate	✓		✓		✓
Nitrite			✓		
Nitrogen in Nitrate+Nitrite			✓	✓	
Phosphate	✓		✓	✓	✓
Sulfate			✓		

* Am-241 and Pu-239/240 data for 216-Z-1A from RHO-ST-17 (1979) used in Phase II screen only; data not listed in HEIS.

✓ = Initial COPC

E3.2 Results of the Phase II COPC Screening Steps

Tables E3-7, E3-8, and E3-9 summarize the results of COPC screening for the successive phases screening at each of the waste sites having COPC data passing the Phase I screen (based on maximum values). The

first column of these tables lists the COPCs and the initial number of soil concentration data for each COPC passing the Phase I screen. The tables list the number of data for each COPC in each successive screening step. The screening step in which an analyte is eliminated as a COPC, i.e., all remaining data for a COPC are screened out, is highlighted in red, and shaded in gray, thereafter.

E3.2.1 Results for 216-A-8

Tables E3-1 and E3-7a summarize the results of COPC screening for 216-A-8. The Phase I screen yielded 17 COPCs listed in the Table E3-2. A majority of these data for most of the remaining COPCs have concentrations levels less than the detection limits, which were eliminated from consideration in Step 1 of the Phase II screen. Aroclor 1254 and selenium were screened out as COPCs in Step 2, because all the remaining data were below either background levels, or the EPA Soil Water Partitioning screening level. Thallium was flagged as tentatively screened out in Step 2 because the remaining two of the three thallium data values above the laboratory detection limits were less than the detection limit values for the Hanford Site-wide soil background (3.7 mg/kg) and the statewide soil background measurements (5 mg/kg) (see Table E3-2). However, thallium was carried forward in the screening process for conservatism. Europium-155 (Eu-155), radium-228, and neptunium-237 were screened out in Step 3 because none of the detected data was above PQL values. Phosphate, potassium-40, gross alpha, and gross beta were screened out as COPCs in Step 4. Phosphate was screened out because it is not regulated for groundwater protection (Ecology, 2009). Potassium-40 was eliminated as a groundwater protection COPC because this analyte is exclusively a naturally occurring radionuclide, and was not an anthropogenic component of the operational waste stream. Gross alpha and gross beta were screened out because they are not radionuclide-specific analytes, their contributions to the alpha and beta/photon emitters MCL dose-rates are not known. Gross alpha and gross beta also have no K_d values, which are necessary for modeling. Thallium, cesium-137, Pu-239/240, and total beta radiostrontium (Sr-90) were screened out in the Step 5 groundwater arrival time screen. Table E3-3 summarizes the maximum depths and K_d values used in this screening step for the 216-A-8 COPCs.

Table E3-3. Maximum Depths of Contamination and COPC K_d Values Used in the Groundwater Arrival Time Screen for the 216-A-8 COPCs Eliminated in the Step 5 Groundwater Arrival Time Screen

216-A-8 COPCs	Maximum Depth (m [ft] bgs)	K_d (mL/g)	K_d Threshold Value	Non-Zero Arrival in <1,000 Years?
Thallium	7.6 (25)	71	0.8	No
Cesium-137	15.7 (51.5)	25	0.8	No
Neptunium-237	7.6 (25)	15	0.8	No
Plutonium-239/240	6.5 (21.5)	200	0.8	No
Total beta radiostrontium (Sr-90)	15.7 (51.5)	25	0.8	No

Four COPCs passed all five screening steps: hexavalent chromium, nitrogen (in nitrate+nitrite), carbon-14, and technetium-99 (Tc-99). It is notable that only one or two data points for each of these COPCs passed the screen. Chapter E4.0 describes how these data were used in the determination of the COPC source term concentrations.

E3.2.2 Results for the 216-Z-8 French Drain

Tables E3-1 and E3-7b summarize the results of COPC screening for 216-Z-8 French Drain for each of the successive phases of screening. The Phase I screen yielded three COPCs listed in the first column of

Table E3-7b, which included Am-241, Pu-238, and Pu-239/240. All three of the transuranic COPCs were screened out in the Step 5 groundwater arrival time screen. The K_d values of 1.2 mL/g for a reference depth of 37 m (122 ft), determined for the 216-Z-9 Crib was used as a conservative threshold for the Step 5 groundwater arrival time screen at 216-Z-8, which is about 300 m (984 ft) northwest of the 216-Z-9 Crib. Use of the 216-Z-9 groundwater arrival time calculations where the depth to groundwater is 59 m (221 ft) bgs for the Step 5 screening at 216-Z-8 was considered to provide a conservative basis for assessing the groundwater arrival time for contaminants at 216-Z-8, where the maximum depth of contamination is only 10.6 m (35 ft) bgs, and the depth to groundwater is comparable (about 72 m [237 ft] bgs in 2007) (ECF-200PW1-3-6-10-0347, *Determination of Vadose Zone Contaminated Soil Volumes and Calculation of COPC Source Term Concentrations for 200-PW-1/3/6 Waste Sites*). Table E3-4 summarizes the maximum depths and K_d values used in this screening step for the 216-Z-8 French Drain COPCs. It should be noted that no source term concentrations were calculated for the 216-Z-8 French Drain since all COPCs were screened out.

Table E3-4. Maximum Depths and K_d Values Used in the Groundwater Arrival Time screen for the 216-Z-8 French Drain COPCs Eliminated in the Step 5 Groundwater Arrival Time Screen

216-Z-8 French Drain COPCs	Maximum Depth (m [ft] bgs)	K_d (mL/g)	K_d Threshold Value	Non-Zero Arrival in <1,000 Years?
Americium-241	10.6 (35)	200	<1.2	No
Plutonium-238	10.6 (35)	200	<1.2	No
Plutonium-239/240	10.6 (35)	200	<1.2	No

E3.2.3 Results for 216-Z-1A

Tables E3-1 and E3-8a summarize the results of COPC screening for 216-Z-1A. The Phase I screen yielded 14 COPCs listed in Table E3-8a, seven of which passed all steps in the Phase II screen. Many of the data for these COPCs have concentrations levels less than the detection limits, which were eliminated from consideration in Step 1 of the Phase II screen. Three COPCs, 1,1,1-trichloroethane, benzene, and ethylbenzene were screened out as COPCs in Step 2 as having no data above detection limits. Three COPCs (barium, cis-1,2-dichloroethylene, and trans-1,2-dichloroethylene) were screened out as COPCs in Step 2 because all the remaining data were below either background levels or the EPA Soil Water Partitioning screening level (toluene, cis-1,2-dichloroethylene, trans-1,2-dichloroethylene). Phosphate was screened out in Step 4 as a COPC not regulated for groundwater protection (Ecology, 2009). Manganese, Am-241, and Pu-239/240 were screened out in the Step 5 groundwater arrival time screen. Table E3-5 summarizes the maximum depths and K_d values used in this screening step for the 216-Z-1A COPCs.

Seven COPCs passed all five screening steps: carbon tetrachloride (CT), chloroform, methylene chloride, 1,1-dichloroethane, tetrachloroethene (PCE), trichloroethylene (TCE), and nitrogen (in nitrate+nitrite). Only one data point passed the screen for nitrogen (in nitrate+nitrite). Chapter E4.0 describes how these data were used in the determination of the COPC source term concentrations.

Table E3-5. Maximum Depths and K_d Values Used in the Groundwater Arrival Time Screen for the 216-Z-1A COPCs Eliminated in the Step 5 Groundwater Arrival Time Screen

216-Z-1A COPCs	Maximum Depth (m [ft] bgs)	K_d (mL/g)	K_d Threshold Value	Non-Zero Arrival in <1,000 Years?
Manganese	43 (140.5)	50	2.84	No
Americium-241	45.7 (150)	200	2.84	No
Plutonium-239/240	44 (145)	200	2.84	No

E3.2.4 Results for 216-Z-18

Tables E3-1 and E3-8b summarize the results of COPC screening for 216-Z-18. The Phase I screen yielded 19 COPCs listed in Tables 3-1 and 3-8b, seven of which passed all steps in the Phase II screen. The analytes 1,1,1-trichloroethane, trichloroethene, and toluene were screened out as COPCs in Step 2, because all the remaining data were below the EPA Soil Water Partitioning screening levels. Phosphate was screened out in Step 4 as a COPC not regulated for groundwater protection (Ecology, 2009). Antimony, barium, beryllium, cobalt, iron, manganese, nickel, and vanadium were screened out in the Step 5 groundwater arrival time screen. Table E3-6 summarizes the maximum depths and K_d values used in this screening step for the 216-Z-18 COPCs. The maximum depths of contamination for all of these COPCs are ≤ 50 m (160 ft) bgs reference depth used in the screen. All of the COPC K_d values are significantly larger than the 2.84 mL/g K_d threshold value for groundwater arrival time of >1,000 years. The depth to groundwater at 216-Z-18 is 73.5 m (235.8 ft) bgs.

Table E3-6. Maximum Depths and K_d Values Used in the Groundwater Arrival Time Screen for the 216-Z-18 COPCs Eliminated in the Step 5 Groundwater Arrival Time Screen

216-Z-18 COPCs	Maximum Depth (m [ft] bgs)	K_d (mL/g)	K_d Threshold Value	Non-Zero Arrival in <1,000 Years?
Antimony	44.6 (146.5)	45	2.84	No
Barium	41.4 (136)	25	2.84	No
Beryllium	10.2 (33.5)	790	2.84	No
Cobalt	18.1 (59.6)	50	2.84	No
Iron	18.1 (59.6)	25	2.84	No
Manganese	39.1 (128.3)	50	2.84	No
Nickel	39.7 (130.5)	65	2.84	No
Vanadium	18.1 (59.6)	1000	2.84	No

Seven COPCs passed all five screening steps: benzene, CT, chloroform, ethylbenzene, methylene chloride, PCE, and nitrogen (in nitrate+nitrite). Three of the COPCs have only one or two data points that passed the screen. Chapter E4.0 describes how these data were used in the determination of the COPC source term concentrations..

E3.2.5 Results for 216-Z-9

Tables E3-1 and E3-9 summarize the results of COPC screening for the 216-Z-9 Crib. The Phase I screen yielded 72 COPCs (Table E3-9). This number of COPCs from the Phase I screen is less than that reported in ECF-200PW1/3/6-10-0360 because nitrate and nitrite in that tally were combined with nitrogen in nitrate+nitrite for the Phase II screen. Much of the data for many of the COPCs were non-detect values, and were removed from consideration in the Step 4 screen.

Barium, lead, mercury, nickel, selenium, silver, vanadium, sulfate, 1,1-dichloroethane, 1,1-dichloroethene, 2-butanone, acetic acid-methyl ester, benzene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, bis(2-ethylhexyl) phthalate, bromomethane, ethylbenzene, naphthalene, and toluene were screened out as COPCs in Step 2, because all the remaining data were below either background levels (antimony and barium), or the EPA Soil Water Partitioning screening level. The radionuclides nickel-63 and protactinium-231 were eliminated in the Step 3 screen because the single remaining data values for each COPC were less than the PQL value. Phosphate, acetonitrile, chloromethane, nitromethane, phenyl sulfone, potassium-40, and the uranium isotopes (U-233, U-234, U-235, U-236, and U-238) were screened out in Step 4. Chloromethane, nitromethane, phenyl sulfone, gross alpha, and gross beta were eliminated as COPCs for groundwater protection as analytes that are either not subject to the ingestion pathway (acetonitrile,⁵ chloromethane², or have no quantifiable or appropriate basis for evaluation as groundwater protection COPCs (nitromethane,⁶ phenyl sulfone³, gross alpha, gross beta). Phosphate was eliminated in the Step 4 screen because phosphate was also detected in the laboratory blanks of the only two data points above the screening levels, and is not regulated for the groundwater pathway. Potassium-40 was eliminated as a groundwater protection COPC in Step 4 because this analyte is exclusively a naturally occurring radionuclide, and was not an anthropogenic component of the operational waste stream.

A number of COPC concentrations for specified sample depths were further evaluated in the Step 4 screen as potential anomalies, especially where isolated occurrence of high K_d analytes were detected at depths inconsistent with the K_d value. Anomalous data above detection limits were observed for cadmium (56.8 m [186.5 ft] bgs), manganese (56.8 m [186.5] ft bgs), and Am-241 (56.8 and 53.5 m [186.5 and 175.5 ft] bgs) in samples from the 299-W-15-46 borehole at the 216-Z-9 Crib. The concentrations of metals and non-mobile radionuclides were not generally detected above the background or Soil-Water-Partitioning screening levels (Table E2-3), except for these analytes at these depths. Based on the review of boring log information combined with laboratory QA results used during data assessment, it is evident that at certain depths the following anomalies exist due to the following sources of field and/or laboratory cross-contamination in the samples:

- The 299-W-15-46 borehole is known to be internally contaminated, ostensibly on the inside of the steel casing (DOE/RL-2006-51, Section 3.2.1.2).
- The stainless steel casing and/or lines, which may have been coated in cadmium, are potential sources of anomalous cadmium and manganese, especially in the presence of the acidic waste discharged to the Crib.
- The laboratory blanks are documented to have been contaminated for samples B17N67 (53.8 m [176.5 ft] bgs) and B17N70 (56.8 m [186.5 ft] bgs) from the 299-W-15-46 borehole.
- The data for anomalously deep occurrences of cadmium, manganese, and Am-241 are all associated with samples B17N67 (53.8 m [176.5 ft] bgs) and B17N70 (56.8 m [186.5 ft] bgs) from the 299-W-15-46 borehole.

⁵ EPA rescinded ingestion reference doses for these analytes.

⁶ No groundwater protectiveness metric (e.g., MCL, or other cleanup level), or criteria (e.g., K_d value).

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Table E3-7. Summary of the COPC Data Screening Results for Each Step in the Phase II COPC Screening Process for Groundwater Protection

Table E3-7a. Summary of Phase II Screening Results for the 216-A-8 Crib

Waste Site	COPCs at Beginning of Phase-II Screen	Phase-II COPC Screen; Step-1	Phase-II COPC Screen; Step-2	COPCs Remaining After Background & Soil-Water Partition Eq. Screen	Phase-II COPC Screen; Step-3	COPCs Remaining After Pathway and Anomalous Data Evaluation Screen	Phase-II COPC Screen; Step-4	COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen	Phase-II COPC Screen; Step-5	Results of Phase-II COPC Screen
#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#
216-A-8	9 Aroclor-1254	1 Aroclor-1254	1 Aroclor-1254	2 Hexavalent Chromium	2 Hexavalent Chromium	2 Hexavalent Chromium	2 Hexavalent Chromium	2 Hexavalent Chromium	2 Hexavalent Chromium	2 Hexavalent Chromium
	9 Hexavalent Chromium	2		3+2(C) Selenium	2 Selenium	2 Selenium	2 Selenium	2 Selenium	2 Selenium	2 Selenium
	7+2(C) Selenium	3 Thallium	3 Thallium	2(0) Thallium	2(0) Thallium	2(0) Thallium	2(0) Thallium	2(0) Thallium	2(0) Thallium	2(0) Thallium
	7+2(B) Phosphate	7+2(C) Phosphate	7+2(B) Phosphate	7+2(B) Phosphate	7+2(B) Phosphate	7+2(B) Phosphate	7+2(B) Phosphate	7+2(B) Phosphate	7+2(B) Phosphate	7+2(B) Phosphate
	9 Nitrogen in Nitrite and Nitrate	10 Nitrogen in Nitrite + Nitrate	10 Nitrogen in Nitrite + Nitrate	1 Nitrogen in Nitrite + Nitrate	1 Nitrogen in Nitrite + Nitrate	1 Nitrogen in Nitrite + Nitrate	1 Nitrogen in Nitrite + Nitrate	1 Nitrogen in Nitrite + Nitrate	1 Nitrogen in Nitrite + Nitrate	1 Nitrogen in Nitrite + Nitrate
	9 Carbon-14	3 Carbon-14	2 Carbon-14	2 Carbon-14	1* Carbon-14	1* Carbon-14	1* Carbon-14	1* Carbon-14	1* Carbon-14	1* Carbon-14
	9 Cesium-137	10 Cesium-137	10 Cesium-137	10 Cesium-137	5 Cesium-137	5 Cesium-137	5 Cesium-137	5 Cesium-137	5 Cesium-137	5 Cesium-137
	9 Europium-155	1 Europium-155	1 Europium-155	1 Europium-155	1 Europium-155	1 Europium-155	1 Europium-155	1 Europium-155	1 Europium-155	1 Europium-155
	9 Radium-228	6 Radium-228	6 Radium-228	6 Radium-228	6 Radium-228	6 Radium-228	6 Radium-228	6 Radium-228	6 Radium-228	6 Radium-228
	4 Neptunium-237	2 Neptunium-237	2 Neptunium-237	2 Neptunium-237	0 Neptunium-237	0 Neptunium-237	0 Neptunium-237	0 Neptunium-237	0 Neptunium-237	0 Neptunium-237
	9 Plutonium-239/240	4 Plutonium-239/240	2 Plutonium-239/240	2 Plutonium-239/240	1 Plutonium-239/240	1 Plutonium-239/240	1 Plutonium-239/240	1 Plutonium-239/240	1 Plutonium-239/240	1 Plutonium-239/240
	9 Potassium-40	7 Potassium-40	1 Potassium-40	1 Potassium-40	1 Potassium-40	1 Potassium-40	1 Potassium-40	1 Potassium-40	1 Potassium-40	1 Potassium-40
	8 Technetium-99	3 Technetium-99	3 Technetium-99	3 Technetium-99	1 Technetium-99	1 Technetium-99	1 Technetium-99	1 Technetium-99	1 Technetium-99	1 Technetium-99
	2 Total beta radiostrontium	2 Total beta radiostrontium	2 Total beta radiostrontium	2 Total beta radiostrontium	1 Total beta radiostrontium	1 Total beta radiostrontium	1 Total beta radiostrontium	1 Total beta radiostrontium	1 Total beta radiostrontium	1 Total beta radiostrontium
	2 Gross alpha	1 Gross alpha	2 Gross alpha	2 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha
	2 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha	1 Gross alpha

Table E3-7b. Summary of Phase II Screening Results for the 216-Z-8 French Drain

Waste Site	COPCs at Beginning of Phase-II Screen	Phase-II COPC Screen; Step-1	Phase-II COPC Screen; Step-2	COPCs Remaining After Quantitation Criteria Screen	Phase-II COPC Screen; Step-3	COPCs Remaining After Pathway and Anomalous Data Evaluation Screen	Phase-II COPC Screen; Step-4	COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen	Phase-II COPC Screen; Step-5	Results of Phase-II COPC Screen
#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#
216-Z-8 French	12 Americium-241	12 Americium-241	12 Americium-241	12 Americium-241	12 Americium-241	12 Americium-241	12 Americium-241	12 Americium-241	12 Americium-241	12 Americium-241
	12 Plutonium-238	12 Plutonium-238	12 Plutonium-238	12 Plutonium-238	12 Plutonium-238	12 Plutonium-238	12 Plutonium-238	12 Plutonium-238	12 Plutonium-238	12 Plutonium-238
	12 Plutonium-239/240	12 Plutonium-239/240	12 Plutonium-239/240	12 Plutonium-239/240	12 Plutonium-239/240	12 Plutonium-239/240	12 Plutonium-239/240	12 Plutonium-239/240	12 Plutonium-239/240	12 Plutonium-239/240

Notes:

Columns labeled # = The number of data values remaining after applicable step in the screening process.
The color code is explained in the legend.

GC/MS = gas chromatograph/mass spectrometer

IDL = instrument detection limit

RDL = required detection limit

LEGEND	COPC not screened out
	Stage where COPC screened out
	Tentatively screened
	COPC Screened out

(J) Denotes estimated values \leq PQL or RDL, and \geq MDL, or estimated concentration for tentatively identified compounds
(E) Estimated value due to interference (Inorganics); Concentration exceeds the calibration range of the GC/MS (Organics)
(B) Detected at a value less than the RDL, but \geq the IDL/MDL (Inorganics); Detected in both the QC blank and the sample (Organics)
(C) Detected in both the sample and the QC blank, and concentration $\leq 5 \times$ the blank concentration (Inorganics)

Table E3-8a. Summary of Phase II Screening Results for the 216-Z-1A Crib

Waste Site	COPCs at Beginning of Phase-II Screen		Phase-II COPC Screen; Step-1		Phase-II COPC Screen; Step-2		Phase-II COPC Screen; Step-3		Phase-II COPC Screen; Step-4		Phase-II COPC Screen; Step-5		Results of Phase-II COPC Screen		
	COPCs Remaining After Phase-I COPC Screen		COPCs Remaining After Lab Code Screen		COPCs Remaining After Background & Soil-Water Partition Eq. Screen		COPCs Remaining After Quantitation Criteria Screen		COPCs Remaining After Pathway and Anomalous Data Evaluation Screen		COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen		COPCs Remaining for Fate and Transport Modeling		
#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC
22	Barium	22	Barium		Barium		Barium		Barium		Barium		Barium		Barium
22	Manganese	22	Manganese	1	Manganese	1	Manganese	1	Manganese	1	Manganese	1	Manganese	1	Manganese
26	Nitrogen in Nitrite and Nitrate	19	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate
1	Phosphate	1	Phosphate	1	Phosphate	1	Phosphate	1	Phosphate	1	Phosphate	1	Phosphate	1	Phosphate
76	1,1-Dichloroethane	3	1,1-Dichloroethane	2(l)	1,1-Dichloroethane	2(l)	1,1-Dichloroethane	2(l)	1,1-Dichloroethane	2(l)	1,1-Dichloroethane	2(l)	1,1-Dichloroethane	2(l)	1,1-Dichloroethane
75	Carbon tetrachloride	75	Carbon tetrachloride	71	Carbon tetrachloride	71	Carbon tetrachloride	71	Carbon tetrachloride	71	Carbon tetrachloride	71	Carbon tetrachloride	71	Carbon tetrachloride
75	Chloroform	18	Chloroform	15	Chloroform	15	Chloroform	15	Chloroform	15	Chloroform	15	Chloroform	15	Chloroform
76	cis-1,2-dichloroethylene	1	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene	cis-1,2-dichloroethylene
75	trans-1,2-dichloroethylene	2	trans-1,2-dichloroethylene	2	trans-1,2-dichloroethylene	2	trans-1,2-dichloroethylene	2	trans-1,2-dichloroethylene	2	trans-1,2-dichloroethylene	2	trans-1,2-dichloroethylene	2	trans-1,2-dichloroethylene
71	Methylene chloride	13	Methylene chloride	13	Methylene chloride	13	Methylene chloride	13	Methylene chloride	13	Methylene chloride	13	Methylene chloride	13	Methylene chloride
76	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene
76	Trichloroethylene	23	Trichloroethylene	23	Trichloroethylene	23	Trichloroethylene	23	Trichloroethylene	23	Trichloroethylene	23	Trichloroethylene	23	Trichloroethylene
459	Americium-241	280	Americium-241	280	Americium-241	280	Americium-241	280	Americium-241	280	Americium-241	280	Americium-241	280	Americium-241
424	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240

Table E3-8b. Summary of Phase II Screening Results for the 216-Z-8 Crib

Waste Site	COPCs at Beginning of Phase-II Screen		Phase-II COPC Screen; Step-1		Phase-II COPC Screen; Step-2		Phase-II COPC Screen; Step-3		Phase-II COPC Screen; Step-4		Phase-II COPC Screen; Step-5		Results of Phase-II COPC Screen		
	COPCs Remaining After Phase-I COPC Screen		COPCs Remaining After Lab Code Screen		COPCs Remaining After Background & Soil-Water Partition Eq. Screen		COPCs Remaining After Quantitation Criteria Screen		COPCs Remaining After Pathway and Anomalous Data Evaluation Screen		COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen		COPCs Remaining for Fate and Transport Modeling		
#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC
30	Antimony	3	Antimony	3	Antimony	3	Antimony	3	Antimony	3	Antimony	3	Antimony	3	Antimony
26	Barium	26	Barium	1	Barium	1	Barium	1	Barium	1	Barium	1	Barium	1	Barium
29	Beryllium	21	Beryllium	1	Beryllium	1	Beryllium	1	Beryllium	1	Beryllium	1	Beryllium	1	Beryllium
28	Cobalt	25	Cobalt	4	Cobalt	4	Cobalt	4	Cobalt	4	Cobalt	4	Cobalt	4	Cobalt
27	Iron	19	Iron	4	Iron	4	Iron	4	Iron	4	Iron	4	Iron	4	Iron
27	Manganese	26	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese
28	Nickel	25	Nickel	2	Nickel	2	Nickel	2	Nickel	2	Nickel	2	Nickel	2	Nickel
27	Vanadium	26	Vanadium	5	Vanadium	5	Vanadium	5	Vanadium	5	Vanadium	5	Vanadium	5	Vanadium
20	Nitrogen in Nitrite and Nitrate	20	Nitrogen in Nitrite and Nitrate	2	Nitrogen as Nitrate	2	Nitrogen as Nitrate	2	Nitrogen as Nitrate	2	Nitrogen as Nitrate	2	Nitrogen as Nitrate	2	Nitrogen as Nitrate
2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate
91	1,1,1-Trichloroethane	3	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane	1,1,1-Trichloroethane
87	Benzene	3	Benzene	1	Benzene	1	Benzene	1	Benzene	1	Benzene	1	Benzene	1	Benzene
87	Carbon tetrachloride	72-12(l)	Carbon tetrachloride	80-10(l)	Carbon tetrachloride	80-10(l)	Carbon tetrachloride	80-10(l)	Carbon tetrachloride	80-10(l)	Carbon tetrachloride	80-10(l)	Carbon tetrachloride	80-10(l)	Carbon tetrachloride
87	Chloroform	9+11(l)	Chloroform	4+2(l)	Chloroform	4+2(l)	Chloroform	4+2(l)	Chloroform	4+2(l)	Chloroform	4+2(l)	Chloroform	4+2(l)	Chloroform
89	Ethylbenzene	7-11(l)	Ethylbenzene	1	Ethylbenzene	1	Ethylbenzene	1	Ethylbenzene	1	Ethylbenzene	1	Ethylbenzene	1	Ethylbenzene
84	Methylene chloride	24	Methylene chloride	23	Methylene chloride	23	Methylene chloride	23	Methylene chloride	23	Methylene chloride	23	Methylene chloride	23	Methylene chloride
89	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene
88	Toluene	28	Toluene	7	Toluene	7	Toluene	7	Toluene	7	Toluene	7	Toluene	7	Toluene
87	Trichloroethylene	3	Trichloroethylene		Trichloroethylene		Trichloroethylene		Trichloroethylene		Trichloroethylene		Trichloroethylene		Trichloroethylene

Notes:

The color code is explained in the legend.

GC/MS = gas chromatograph/mass spectrometer

IDL = instrument detection limit

RDL = required detection limit

LEGEND	
COPC not screened out	
Stage where COPC screened out	
Tentatively screened	
COPC Screened out	

(J) Denotes estimated values \leq PQL or RDL, and \geq MDL, or estimated concentration for tentatively identified compounds

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Table E3-9. Summary of the COPC Data Screening Results for Each Step in the Phase II COPC Screening Process for Groundwater Protection for the 216-Z-9 Crib

Waste Site	COPCs at Beginning of Phase-II Screen		Phase-II COPC Screen; Step-1		Phase-II COPC Screen; Step-2		Phase-II COPC Screen; Step-3		Phase-II COPC Screen; Step-4		Phase-II COPC Screen; Step-5		Results of Phase-II COPC Screen		
	COPCs Remaining After Phase-I COPC Screen		COPCs Remaining After Lab Code Screen		COPCs Remaining After Background & Soil-Water Partition Eq. Screen		COPCs Remaining After Quantitation Criteria Screen		COPCs Remaining After Pathway and Anomalous Data Evaluation Screen		COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen		COPCs Remaining for Fate and Transport Modeling		
#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC
53	Antimony	19	Antimony	1	Antimony	1	Antimony	1	Antimony	1	Antimony	1	Antimony	1	Antimony
22	Arsenic	18	Arsenic	3	Arsenic	3	Arsenic	3	Arsenic	3	Arsenic	3	Arsenic	3	Arsenic
72	Barium	72	Barium		Barium		Barium		Barium		Barium		Barium		Barium
48	Cadmium	34	Cadmium	16	Cadmium	16	Cadmium	16	Cadmium	16	Cadmium	16	Cadmium	16	Cadmium
69	Cobalt	69	Cobalt	3	Cobalt	3	Cobalt	3	Cobalt	3	Cobalt	3	Cobalt	3	Cobalt
72	Copper	72	Copper	1	Copper	1	Copper	1	Copper	1	Copper	1	Copper	1	Copper
18	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium
69	Iron	69	Iron	4	Iron	4	Iron	4	Iron	4	Iron	4	Iron	4	Iron
24	Lead	24	Lead		Lead		Lead		Lead		Lead		Lead		Lead
72	Manganese	72	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese
48	Mercury	21	Mercury		Mercury		Mercury		Mercury		Mercury		Mercury		Mercury
72	Nickel	72	Nickel		Nickel		Nickel		Nickel		Nickel		Nickel		Nickel
22	Selenium	10	Selenium		Selenium		Selenium		Selenium		Selenium		Selenium		Selenium
59	Silver	19	Silver		Silver		Silver		Silver		Silver		Silver		Silver
69	Vanadium	69	Vanadium		Vanadium		Vanadium		Vanadium		Vanadium		Vanadium		Vanadium
56	Nitrogen in Nitrite and Nitrate	55	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate
46	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate
30	Sulfate	28	Sulfate		Sulfate		Sulfate		Sulfate		Sulfate		Sulfate		Sulfate
18	Acroclor-1248	4	Acroclor-1248	4	Acroclor-1248	4	Acroclor-1248	4	Acroclor-1248	4	Acroclor-1248	4	Acroclor-1248	4	Acroclor-1248
130	1,1,2,2-Tetrachloroethane	3(0)	1,1,2,2-Tetrachloroethane	2(0)	1,1,2,2-Tetrachloroethane	3(0)	1,1,2,2-Tetrachloroethane	3(0)	1,1,2,2-Tetrachloroethane	3(0)	1,1,2,2-Tetrachloroethane	3(0)	1,1,2,2-Tetrachloroethane	3(0)	1,1,2,2-Tetrachloroethane
129	1,1,2-Trichloroethane	2	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane
31	1,1-Dichloroethane	2	1,1-Dichloroethane		1,1-Dichloroethane		1,1-Dichloroethane		1,1-Dichloroethane		1,1-Dichloroethane		1,1-Dichloroethane		1,1-Dichloroethane
138	1,1-Dichloroethene	1+1(l)	1,1-Dichloroethene		1,1-Dichloroethene		1,1-Dichloroethene		1,1-Dichloroethene		1,1-Dichloroethene		1,1-Dichloroethene		1,1-Dichloroethene
53	1-Butanol	8+8(l)	1-Butanol	7(l)	1-Butanol	7(l)	1-Butanol	7(l)	1-Butanol	7(l)	1-Butanol	7(l)	1-Butanol	7(l)	1-Butanol
138	2-Butanone	29+20(l)	2-Butanone	0	2-Butanone	0	2-Butanone	0	2-Butanone	0	2-Butanone	0	2-Butanone	0	2-Butanone
21	Acetic acid, methyl ester	2(l)	Acetic acid, methyl ester	0	Acetic acid, methyl ester	0	Acetic acid, methyl ester	0	Acetic acid, methyl ester	0	Acetic acid, methyl ester	0	Acetic acid, methyl ester	0	Acetic acid, methyl ester
49	Acetonitrile	1+6(l)	Acetonitrile	1+6(l)	Acetonitrile	1+6(l)	Acetonitrile	1+6(l)	Acetonitrile	1+6(l)	Acetonitrile	1+6(l)	Acetonitrile	1+6(l)	Acetonitrile
169	Benzene	3+5(l)	Benzene		Benzene		Benzene		Benzene		Benzene		Benzene		Benzene
65	Benz(a)anthracene	1(l)	Benz(a)anthracene		Benz(a)anthracene		Benz(a)anthracene		Benz(a)anthracene		Benz(a)anthracene		Benz(a)anthracene		Benz(a)anthracene
65	Benz(o)pyrene	1(l)	Benz(o)pyrene		Benz(o)pyrene		Benz(o)pyrene		Benz(o)pyrene		Benz(o)pyrene		Benz(o)pyrene		Benz(o)pyrene
65	Benzofluoranthene	1(l)	Benzofluoranthene		Benzofluoranthene		Benzofluoranthene		Benzofluoranthene		Benzofluoranthene		Benzofluoranthene		Benzofluoranthene
65	Bis(2-ethylhexyl) phthalate	10+15(l)	Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate
132	Bromodichloromethane	2	Bromodichloromethane		Bromodichloromethane		Bromodichloromethane		Bromodichloromethane		Bromodichloromethane		Bromodichloromethane		Bromodichloromethane
132	Bromoform	2	Bromoform		Bromoform		Bromoform		Bromoform		Bromoform		Bromoform		Bromoform
129	Bromomethane	1+1(l)	Bromomethane		Bromomethane		Bromomethane		Bromomethane		Bromomethane		Bromomethane		Bromomethane
393	Carbon tetrachloride	227+39(l)	Carbon tetrachloride	179+33(l)	Carbon tetrachloride	179+33(l)	Carbon tetrachloride	179+33(l)	Carbon tetrachloride	179+33(l)	Carbon tetrachloride	179+33(l)	Carbon tetrachloride	179+33(l)	Carbon tetrachloride
393	Chloroform	243+39(l)	Chloroform	67+14(l)	Chloroform	67+14(l)	Chloroform	67+14(l)	Chloroform	67+14(l)	Chloroform	67+14(l)	Chloroform	67+14(l)	Chloroform
138	Chloromethane	1+1(l)	Chloromethane	1+1(l)	Chloromethane	1+1(l)	Chloromethane	1+1(l)	Chloromethane	1+1(l)	Chloromethane	1+1(l)	Chloromethane	1+1(l)	Chloromethane

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Notes:
 Columns labeled # = The number of data values remaining after applicable step in the screening process.
 The color code is explained in the legend.

GC/MS = gas chromatograph/mass spectrometer
 IDL = instrument detection limit
 RDL = required detection limit

LEGEND	COPC not screened out		
	Stage where COPC screened out	Tentatively screened	COPC Screened out

(J) Denotes estimated values \leq PQL or RDL, and \geq MDL, or estimated concentration for tentatively identified compounds
(E) Estimated value due to interference (Inorganics); Concentration exceeds the calibration range of the GC/MS (Organics)
(B) Detected at a value less than the RDL, but \geq the IDL/MDL (Inorganics); Detected in both the QC blank and the sample (Organics)
(C) Detected in both the sample and the QC blank, and concentration $\leq 5 \times$ the blank concentration (Inorganics)

Table E3-9. Summary of the COPC Data Screening Results for Groundwater Protection for the 216-Z-9 Crib

Waste Site	COPCs at Beginning of Phase-II Screen	Phase-II COPC Screen; Step-1	Phase-II COPC Screen; Step-2	Phase-II COPC Screen; Step-3	Phase-II COPC Screen; Step-4	Phase-II COPC Screen; Step-5	Results of Phase-II COPC Screen
#	COPC	#	COPC	#	COPC	#	COPC
169	Ethylbenzene	1+3(l)	Ethylbenzene				
70	Hexachloroethane	8+1(l)	Hexachloroethane	6	Hexachloroethane	6	Hexachloroethane
170	Methylene chloride	58+1(l)	Methylene chloride	13+1(l)	Methylene chloride	13+1(l)	Methylene chloride
71	Naphthalene	1(l)	Naphthalene		Naphthalene		Naphthalene
1	Nitromethane	1	Nitromethane	1	Nitromethane	1	Nitromethane
74	Pentachlorophenol	1(l)	Pentachlorophenol	1	Pentachlorophenol	1	Pentachlorophenol
1(l)	Phenyl sulfone	1(l)	Phenyl sulfone	1(l)	Phenyl sulfone	1(l)	Phenyl sulfone
169	Tetrachloroethene	41+12(l)	Tetrachloroethene	29+11(l)	Tetrachloroethene	29+11(l)	Tetrachloroethene
169	Toluene	27	Toluene		Toluene		Toluene
86	Tributyl phosphate	12+7(l)	Tributyl phosphate	12	Tributyl phosphate	12	Tributyl phosphate
395	Trichloroethylene	4+9(l)	Trichloroethylene	1	Trichloroethylene	1	Trichloroethylene
159	Americium-241	71	Americium-241	71	Americium-241	64	Americium-241
59	Europium-152	3	Europium-152	2	Europium-152	2	Europium-152
59	(Gadolinium-152, Eu-152 D)	3	Gadolinium-152 (Eu-152 D)	2	Gadolinium-152 (Eu-152 D)	2	Gadolinium-152 (Eu-152 D)
59	Europium-154	1	Europium-154	1	Europium-154	1	Europium-154
59	Europium-155	3	Europium-155	3	Europium-155	1	Europium-155
9	Gross alpha	9	Gross alpha	9	Gross alpha	9	Gross alpha
9	Gross beta	9	Gross beta	9	Gross beta	9	Gross beta
23	Neptunium-237	5	Neptunium-237	5	Neptunium-237	4	Neptunium-237
4	Nickel-63	1	Nickel-63		Nickel-63		Nickel-63
116	Plutonium-238	22	Plutonium-238	22	Plutonium-238	10	Plutonium-238
55	Plutonium-239/240	24	Plutonium-239/240	24	Plutonium-239/240	22	Plutonium-239/240
46	Potassium-40	41	Potassium-40	15	Potassium-40	14	Potassium-40
4	Protactinium-231	1	Protactinium-231	1	Protactinium-231	1	Protactinium-231
47	Radium-226	38	Radium-226	12	Radium-226	10	Radium-226
47	Radium-228	37	Radium-228	37	Radium-228	33	Radium-228
3	Srontium-90	2	Srontium-90	2	Srontium-90	2	Srontium-90
43	Total beta radiostrontium	2+2(l)	Total beta radiostrontium	2	Total beta radiostrontium	1	Total beta radiostrontium
16	Technetium-99	5	Technetium-99	4	Technetium-99	3	Technetium-99
14	Thorium-230	2+2(l)	Thorium-230	2+2(l)	Thorium-230	1+2(l)	Thorium-230
5	Uranium-233	1	Uranium-233	1	Uranium-233	1	Uranium-233
67	Uranium-234	61	Uranium-234	16	Uranium-234	13	Uranium-234
129	Uranium-235	24+3(l)	Uranium-235	6+1(l)	Uranium-235	1	Uranium-235
5	Uranium-236	3	Uranium-236	3	Uranium-236	3	Uranium-236
85	Uranium-238	69	Uranium-238	2	Uranium-238	2	Uranium-238
291	Uranium (combined)	165	Uranium (combined)	28	Uranium (combined)	19	Uranium (combined)
						2	Uranium (combined)

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Notes:
 Columns labeled # = The number of data values remaining after applicable step in the screening process.
 The color code is explained in the legend.

GC/MS = gas chromatograph/mass spectrometer
 IDL = instrument detection limit
 RDL = required detection limit

LEGEND	COPC not screened out	Stage where COPC screened out	Tentatively screened	COPC Screened out

(J) Denotes estimated values \leq PQL or RDL, and \geq MDL, or estimated concentration for tentatively identified compounds
(E) Estimated value due to interference (Inorganics); Concentration exceeds the calibration range of the GC/MS (Organics)
(B) Detected at a value less than the RDL, but \leq the IDL/MDL (Inorganics); Detected in both the QC blank and the sample (Organics)
(C) Detected in both the sample and the QC blank, and concentration $\leq 5 \times$ the blank concentration (Inorganics)

Based on this information, the data for these analytes at these depths were interpreted to be anomalous, and were omitted from further evaluation in the screening process. The maximum depths of contamination for the remaining data for all of the COPCs, except for manganese, are \leq the 37.2 m (122 ft) reference depth used for most of the groundwater arrival time screen in Step 5. It is notable that only one manganese value above the screening level remained for samples deeper than 31.8 m (104.5 ft). Although this manganese data point (520 mg/kg), at 48.3 m (158.4 ft) bgs, was carried forward to the Step 5 screen, it is the value is only about 3 percent larger than the background screening level, and significantly less than the State background level for eastern Washington (Ecology Publication 94-115, *Natural Background Soil Metals Concentrations in Washington State*).

The evaluation of the uranium isotopes and uranium as an inorganic analyte were reassigned to the combination of all uranium isotopes because EPA regulates uranium impacts to groundwater as total uranium (40 CFR 141.25[a], "National Primary Drinking Water Regulations," "Analytical Methods for Radioactivity"). Only the uranium isotopic data were evaluated in the COPC screening beyond Step 2, because all of the uranium metal data were below background levels. The uranium isotopic data remaining at Step 4 of the COPC screening process were then evaluated in the following manner. The uranium isotopic activities for each sample were added, converted from activity unity (pCi/g) to concentration units (mg/kg) using the specific activities of each isotope. The total uranium concentrations were then compared to the 90th percentile of the soil background population. This process yielded only two samples with concentrations that exceeded the uranium background screening metric. The data for these two samples were then carried forward to the subsequent stages of the COPC screening process as uranium (combined).

Twenty-one (21) COPCs (7 inorganic analytes, 3 organic compounds, and 11 radionuclides) were screened out in the Step 5 groundwater arrival time/half-life screen. Table E3-10 summarizes the maximum depths and K_d values used in this screening step for the 216-Z-1A COPCs.

Three of the radionuclides (Eu-152, Eu-154, and radium-228 [Ra-228]) were screened out by half-life. Tables E3-11 and E3-12 summarize the information used in the half-life screening step. As indicated in these tables, the time required for any non-zero impact to groundwater is significantly greater than 10 half-lives of the parent and/or decay products for these COPCs. Thus, these radionuclides are eliminated as groundwater protection COPCs because they have decayed to one or more stable non-hazardous isotopes by the time they reach groundwater. It is also indicated from the information in these tables that Eu-152 ($K_d = 1.0$ mL/g) is not screened out by groundwater arrival time (K_d threshold values for >1,000 year arrival time = 1.2 mL/g), and cannot be screened out by half-life alone (13.5 yrs) because it has a long-lived daughter isotope (gadolinium-152 [Gd-152]; 10^{14} yrs). Due to the combination of the short half-life of the Eu-152 parent, and the very large K_d value (240 mL/g) of the long-lived daughter isotope, this COPC can be screened out indirectly by groundwater arrival because the Gd-152 daughter isotope requires > 1,000 years to reach groundwater.

Fifteen (15) COPCs had some data that passed all five screening steps: hexavalent chromium, nitrogen (in nitrate+nitrite), 1,1,2,2-tetrachloroethane, 1-butanol, CT, chloroform, methylene chloride, 1,1-dichloroethane, PCE, TCE, 1,1,2-trichloroethane, bromodichloromethane, bromoform, pentachlorophenol, Tc-99, and uranium (combined). It is notable that there were only 1 to 3 data points passing the screen for 10 of the 15 COPCs nitrogen (in nitrate+nitrite). Chapter E4.0 describes how these data were used in the determination of the COPC source term concentrations.

Table E3-10. Maximum Depths, K_d Values, and K_d Threshold Values Used in the Step 5 Groundwater Arrival Time Screen for the 216-Z-9 COPCs

216-Z-9 COPCs	Maximum Depth (m [ft] bgs)	K _d (mL/g)	K _d Threshold Value	Non-Zero Arrival in <1000 Years?
Antimony	149	45	8.5	No
Arsenic	34.4 (113)	29	1.2	No
Cadmium	37.2 (122)	30	12	No
Cobalt	37.2 (122)	30	1.2	No
Copper	31.8 (104.5)	22	1.2	No
Iron	37.2 (122)	25	1.2	No
Manganese	48.2 (158.4)	50	8.5	No
Aroclor-1248	21.9 (72)	44	1.2	No
Hexachloroethane	22.8 (75)	1.8	1.2	No
Tributyl phosphate	33.2 (109)	1.9	1.2	No
Americium-241	37.2 (122)	200	1.2	No
Europium-152+D	34.3 (112.5)	1	1.2	Yes
Europium-154+D	34.3 (112.5)	1	1.2	Yes
Europium-155	34.3 (112.5)	1	1.2	Yes
Neptunium-237	37.9 (124.5)	15	1.2	No
Nickel-63	35.8 (117.5)	30	1.2	No
Plutonium-238	37.2 (122)	200	1.2	No
Plutonium-239/240	37.2 (122)	200	1.2	No
Protactinium-231	35.8 (117.5)	550	1.2	No
Radium-226+D	38.2 (125.4)	3	1.2	No
Radium-228+D	59.4 (195)	3	15	Yes
Strontium-90	34.3 (112.5)	25	1.2	No
Total beta radiostrontium	34.3 (112.5)	225	1.2	No
Thorium-230	36.3 (119)	200	1.2	No

Notes:

The maximum depths of contamination for most COPCs are less than, and/or sufficiently close to, the 37.2 m (122 ft) reference depth for which the K_d threshold value is 1.2 mL/g. The K_d threshold values for the COPCs with a maximum depth of contamination deeper than the approximately 37 m (121 ft) reference depth are also listed. The COPCs with K_d values greater than the threshold K_d values; i.e., non-zero groundwater arrival time >1,000 years, were screened out in Step 5. The depth to groundwater at 216-Z-9 is 59 m (221 ft) bgs.

Table E3-11. Half-Lives of Selected Radionuclide COPC Parents, and Decay Products

Parent Isotope	Half-Life	Decay Mode	Decay Product	Half-life	Decay Product	Half-Life	Decay Mode	Decay Product	Half-Life	Decay Product(s)	Ten Half-Lives
Eu-152	13.5 yrs	ec	Sm-152	Stable							135 yrs
				10^{14} yrs	Other long-lived daughters						>1,000 Years
Eu-154	8.6 yrs	ec	Sm-144	Stable							86 Years
				β^-	Gd-152						
Eu-155	4.8 yrs	β^-	Gd-154	Stable							48 yrs
Ra-226	1,026 yrs	α	Gd-155	Stable							>1,000 Years
Ra-228	5.75 yrs	β^-	Ac-228	6.15 hrs	β^-	Th-228	1.92 yrs	α	Ra-224	3.6 days	To stable Pb-208 with other decays with half-lives <1 min
											58 Years

Notes:

Determinant half-life values (longest in the parent or decay product) used to define the 10X half-life metric for comparison to K_d-based groundwater arrival time used in the screening.

Ac-228	=	actinium-228	Ra-224	=	radium-224
Eu-152	=	euroium-152	Ra-226	=	radium-226
Eu-154	=	euroium-154	Ra-228	=	radium-228
Eu-155	=	euroium-155	Rn-222	=	radon-222
Gd-152	=	gadolinium-152	Sm-144	=	samarium-144
Gd-154	=	gadolinium-154	Sm-152	=	samarium-152
Gd-155	=	gadolinium-155	Th-228	=	thorium-228
Pb-208	=	lead-208			

Table E3-12 Comparison of the Groundwater Arrival Time for the First Non-Zero Impact to Groundwater from Radionuclide COPCs

Isotope	Maximum Depth (m [ft] bgs)	K _d (mL/g)	Time to First Non-Zero Impact to Groundwater	Ten Half-Lives	Ten Half-Lives < Time to Groundwater Impact (Screened Out)	Non-Zero Arrival in >1000 Years (Screened Out)
Gadolinium-152 (from europium-152)	34.3 (112.5)	240	>1,000 years*	NA		Yes
Europium -154	34.3 (112.5)	1	> 900 years	86 Years	Yes	---
Europium -155	34.3 (112.5)	1	> 900 years	48 Years	Yes	---
Radium-226	38.1 (125)	3	> 1,000 years*	NA		Yes
Radium-228	59.4 (195)	3	120 years	58 Years	Yes	---

Notes:

Comparison is at the maximum depth of contamination beneath the 216-Z-9 Crib, to the radionuclide 10^x half-life metric used in the Step 5 COPC screen.* Contaminants at ≤38 m (125 ft) bgs, with K_d > 1.2 have groundwater arrival time >1,000 years.

NA = not applicable

E4.0 Determination of Contaminated Soil Volumes and Source Term Concentrations for the 200-PW-1/3/6 Waste Sites

This chapter describes the process used to estimate a) the contaminated soil volumes in the vadose zone beneath the 200-PW-1/3/6 waste sites, and b) the source term concentrations for the contaminated soil volumes at the waste sites. Fate and transport modeling for the evaluation of potential impacts to groundwater from vadose zone contamination beneath the 200-PW-1/3/6 OU waste sites requires reasonable estimates of the contaminated soil volumes and representative concentrations within the soil volumes. Fate and transport modeling was used to evaluate the groundwater impacts for the screened COPCs for the 216-Z-9, 216-Z-1A, 216-Z-18, and the 216-A-8 waste sites.

E4.1 Background: The Use of Contaminated Soil Volume and Concentration Data in Fate and Transport Modeling

The source term used in forward fate and transport modeling requires assignment of: (a) one or more contaminated soil volumes, and (b) a COPC soil concentration for the calculation of contaminant mass in the model. Equation E4-1 summarizes the relationships between the source term mass, concentration, and the contaminated soil volume given by the thickness (depth interval) and lateral dimensions (length and width of the volume).

Equation E4-1

$$\text{Mass}_C = \text{Conc}_C \times \text{Bulk density}_S \times \text{Volume}_S$$

$$\text{In units of: } \text{kg}_C = (\text{mg}_C/\text{kgs}) \times (\text{kg}/\text{m}^3) \times \text{m}^3 \times (1\text{E}-06 \text{ Kg}_C/\text{mg}_C)$$

where:

Volume_S = Volume of the contaminated soil (S) volume

$\text{Volume} = \text{length (L)} \times \text{width (W)} \times \text{height (H)}$

Mass_C = contaminant (C) mass

Conc_C = contaminant source term concentration

The source term mass calculated in two-dimensional (2-D) vadose zone modeling is based on the use of a contaminated source term volume. This is represented by the lateral dimension of the contaminated soil volume parallel to the direction of groundwater flow (length [L]), and the thickness of the soil volume (H), for each 1 m (3.3-ft) wide soil volume (W) (see Section E5.4). The COPC soil concentration used in the calculation is intended to be a value that represents the overall concentration within the entire contaminated soil volume for the purpose of calculating and/or conservatively estimating the source term COPC mass (or activity).

Thus, the determination of both the contaminated soil volume and the soil concentration requires a rationale and technical basis for the manner in which they are determined. The determination of contaminated soil volume(s) and concentration(s) for use in modeling can be simplistic, e.g. a single volume and concentration, or more sophisticated, e.g., multiple volumes each with a representative concentration. The approach used here involved the determination of multiple volumes and concentrations for each waste site. The following sections describe the rationale and process used in the determination of contaminated soil volumes, and in the determination of the COPC soil concentration values for the soil volumes at each of the waste sites for which vadose zone fate and transport modeling was performed.

E4.2 Determination of Contaminated Soil Volumes

The following steps were used in the process for the determination of the contaminated soil volumes and calculation of the source term concentrations for the 216-Z-9, 216-Z-1A, and 216-Z-18, and 216-A-8 waste sites:

1. Determination of the depth intervals and thicknesses of the contaminated soil volumes in the vadose zone beneath each of the waste sites based on the stratigraphic units, thicknesses, and depths in which contaminants preferentially occur
2. Binning of the data for each of the COPCs within the contaminated depth interval identified for the waste sites
3. Calculation of summary statistical values for the COPC data within each of the contaminated soil volumes, at each waste site, as appropriate
4. Determination of reasonable bounding dimensions of the lateral extent of contaminated soil volumes to be used in the modeling based on evaluation of the following:
 - COPC concentration patterns in north-south (N-S), and east-west (E-W) transects across the waste sites constructed from borehole data
 - Soil concentration isopleths (contours) constructed from the soil data
 - Evaluation of three-dimensional (3-D) plumes constructed for representative COPCs at the 216-Z-9 waste site
5. Comparative evaluation of the weight of evidence for constraining the lateral dimensions of the contaminated soil volumes at the waste sites
6. Comparison of methods for estimating representative COPC concentrations for the soil volumes
7. Consideration of the uncertainties, assumptions, and biases associated with estimated contaminant source term concentrations

The source term concentrations and dimensions of the contaminated soil volumes are then provided as input parameters for the vadose zone fate and transport modeling. The modeling is the tool by which potential impacts to groundwater are evaluated, and by which the risk for this pathway is characterized.

E4.2.1 Identification of the Stratigraphic Units, Thicknesses and Depths of Contamination

The identification of the geology and stratigraphic units in the vadose zone beneath the waste sites is a prerequisite to the determination of the depth intervals and thicknesses of the contaminated soil volumes. Section 2.2.3 of the feasibility study describes the general geologic relationships for the 200-PW-1/3/6 OU. The detailed stratigraphy for each of the representative waste sites was based on the information from the original driller logs and/or the stratigraphic sections prepared from them archived in the Well Information and Document Lookup database, as well as the 3-D geologic relationships developed from a composite of all boreholes in the vicinities of the waste sites (PNNL-16198, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and 216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*, and Figure 2.4 in PNNL-15914, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-9 Trench at the Hanford Site: Heterogeneous Model Development and Soil Vapor Extraction Modeling*).

The geologic information for the reference boreholes identified in Figure E4-1 was used to describe the detailed stratigraphy for the waste sites.

A summary of the detailed stratigraphic relationships for specific boreholes from the three representative waste sites (216-Z-9, 216-Z-1A & 216-Z-18, and 216-A-8) are illustrated in Figure E4-1. The stratigraphic relationships for the 216-Z-1A Crib were also used for the 216-Z-18 Crib approximately 50 m (164 ft) southwest of the 216-Z-1A Crib.

Identification of the lateral dimensions and specific depths and depth intervals of vadose zone contamination is important for fate and transport modeling for the following reasons:

- The contamination in the vadose zone is not spatially uniform.
- The contamination occurs primarily within specific sediment types and over specific depth intervals (H).
- Calculated estimates of the amounts of contamination (source term mass; Mass_c) in the vadose zone are based on the dimensions of the contaminated soil volumes.

The identification of discrete contamination depth intervals within the stratigraphic sequence is also an important basis for the calculation of contaminated soil volumes because it represents a refinement from the practice of more arbitrary and/or less representative methods of estimating depth intervals and soil volumes. This refinement also serves to reduce the uncertainty associated with the estimation of contaminated soil volume, source term (contaminant) masses, and resulting groundwater impacts compared to those determined by more arbitrary methods that tend to be unrepresentative and larger.

E4.2.2 Waste Site Stratigraphy, Contaminant Depth Profiles, and Depth Intervals of Contamination

Depth profiles for the contaminants passing the COPC screening and evaluation process at each of the waste sites were compared to the detailed stratigraphic subdivision depths to evaluate correlations between lithologies and preferentially contaminated depth intervals. Detailed descriptions of the representative vadose zone stratigraphies for the waste sites were prepared from driller logs and/or the stratigraphic sections prepared from them (PNNL-16198; PNNL-15914). The detailed stratigraphic information was utilized in several ways that include the following:

- Elucidation of the actual geology and stratigraphy of the vadose zone beneath the waste sites prior to simplification; e.g., modeling
- A basis for understanding the less detailed simplification of the actual stratigraphy used in the modeling
- Comparison of depth profiles for COPCs to lithologies in the actual vs. simplified stratigraphies to evaluate depth concentration correlations

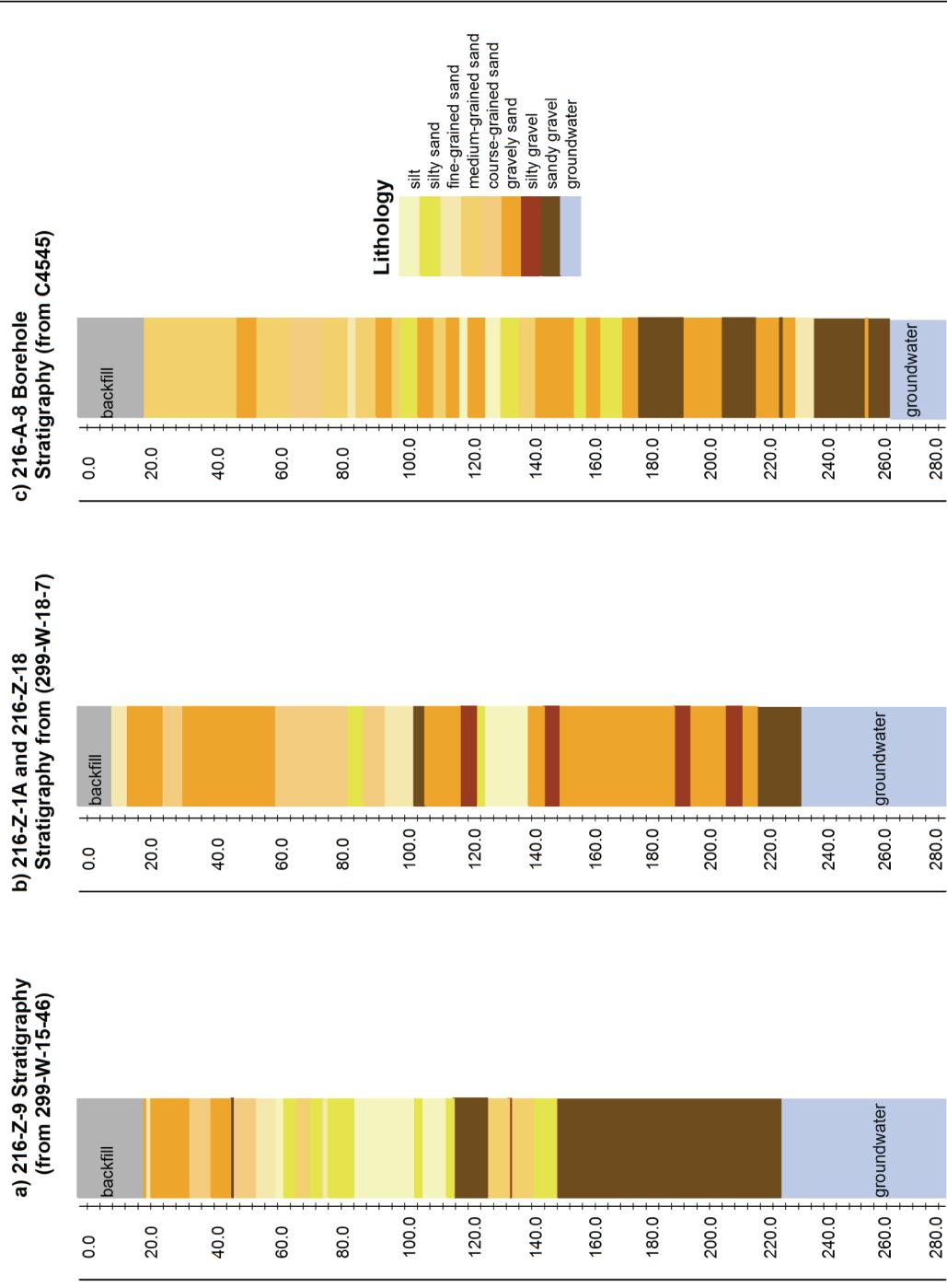


Figure E4-1. Detailed Stratigraphy in the Vadose Zone Beneath (a) the 216-Z-9 Waste Site, (b) 216-Z-1A and 216-Z-18 Waste Sites, and (c) the 216-A-8 Waste Site

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The depth intervals, over which most of the vadose zone contamination occurs, appear to be correlated with specific lithologies and facies in the stratigraphic sequences that at all four waste sites tend to be units containing finer-grained sediments and/or some calcareous components, with less contamination in the coarser-grained sediments. This general pattern of contaminant behavior is apparent from borehole to borehole for all of the waste sites evaluated, corroborating similar observations from previous investigations of these waste sites, as cited in the following documents:

- DOE/RL-2006-51, *Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units*
- DOE/RL-2006-58, *Carbon Tetrachloride Dense Non-Aqueous Phase Liquid (DNAPL) Source Term Interim Characterization Report*
- PNNL-14895, *Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site*
- PNNL-15914, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-9 Trench at the Hanford Site: Heterogeneous Model Development and Soil Vapor Extraction Modeling*
- PNNL-16198, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and 216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*

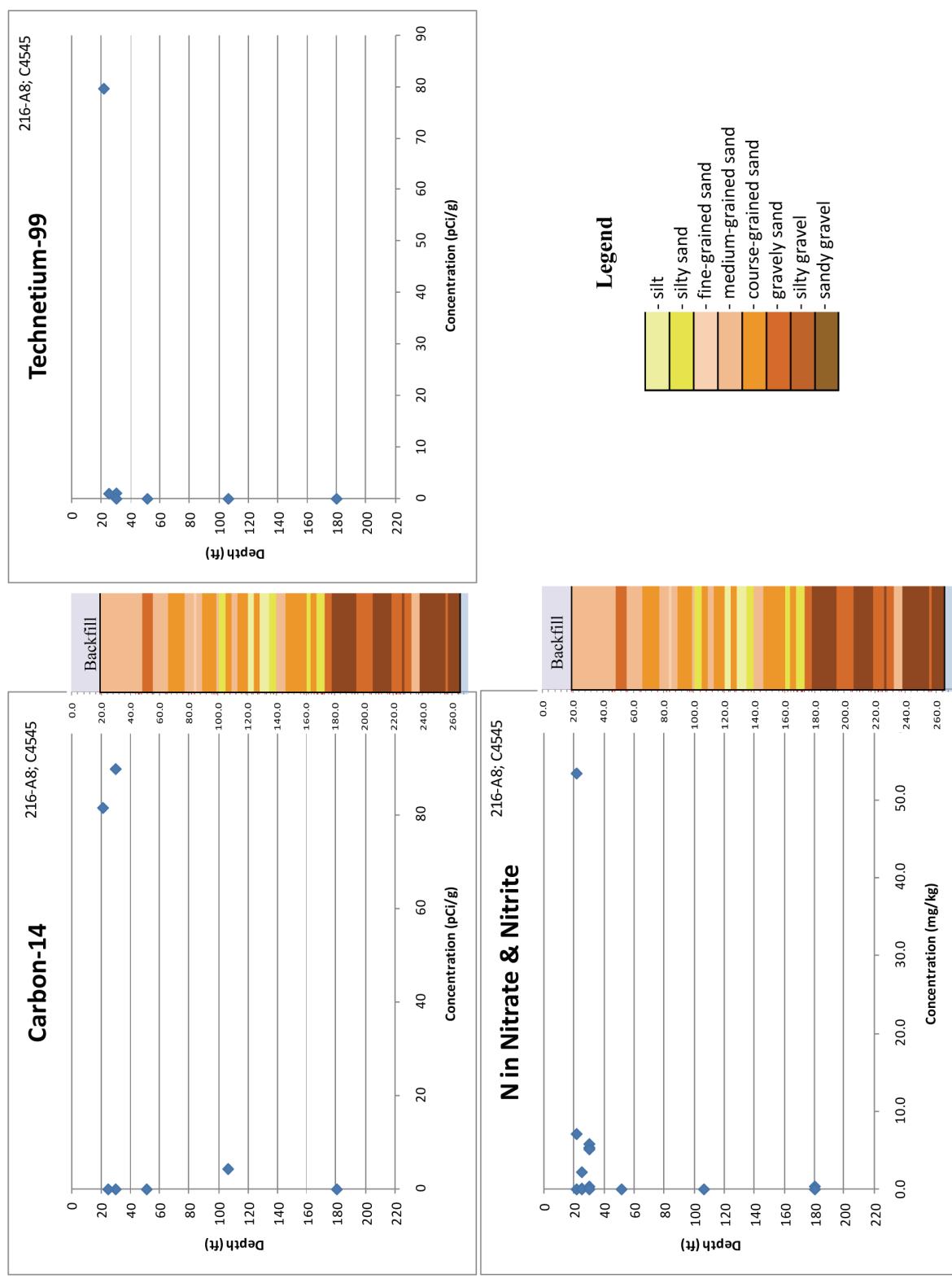
Thus, this aspect of the contaminant behavior conceptual model is an important factor in the understanding of the nature and extent of contamination in the vadose zone and thus, also important for the determination of the depth intervals of contaminated soil volumes used as source terms in the modeling.

Examples of the correlation between COPC soil concentration and stratigraphy are illustrated in Figures E4-2 and E4-3, which show concentration depth profiles for selected COPCs in the context of the vadose zone stratigraphy beneath the 216-A-8, 216-Z-1A⁷ and 216-Z-9 cribs. The depth intervals within which screened COPC data occur were, therefore, determined and grouped primarily based on stratigraphy and lithology to establish the specific intervals for use in the fate and transport modeling. Thus, the contaminated soils in the Hanford formation (+/- the Ringold Formation) can best be described as occurring in discrete lithologic layers within the geologic units or formations, e.g., discrete layers within a main subdivision (H1, H2, or H3 units) of the Hanford formation. Based on the general stratigraphic relationships, most of the units and layers can be reasonably regarded as continuous tabular units within the modeling domain for vadose zone modeling.

E4.2.3 Merging Z-Area Contaminated Depth Intervals Within a 3-D Geologic Framework

The geologic framework for the fate and transport modeling utilized the 3-D stratigraphy developed for the entire domain of the Z-Area waste sites based on the compilation and evaluation of geologic data from 215 boreholes and a comprehensive effort to correlate units and define the main geologic contacts (PNNL-14895; PNNL-15914; PNNL-16198). Thus, the domain-wide stratigraphy (Figure E4-4) was used for the modeling as best representing the main generalized geologic subdivisions in the vadose zone beneath the 216-Z-1A, 216-Z-18, and 216-Z-9 waste sites for assigning hydrogeologic properties in the modeling and depth intervals, particularly for the Cold Creek units.

⁷ The stratigraphic relationships and contaminant depth intervals for the 216-Z-1A crib were also used for the 216-Z-18 Crib approximately 50 m (164 ft) southwest of the 216-Z-1A Crib.



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Figure E4-2a. Concentration-Depth Profiles for 216-A-8, Based on Stratigraphy from Borehole C4545

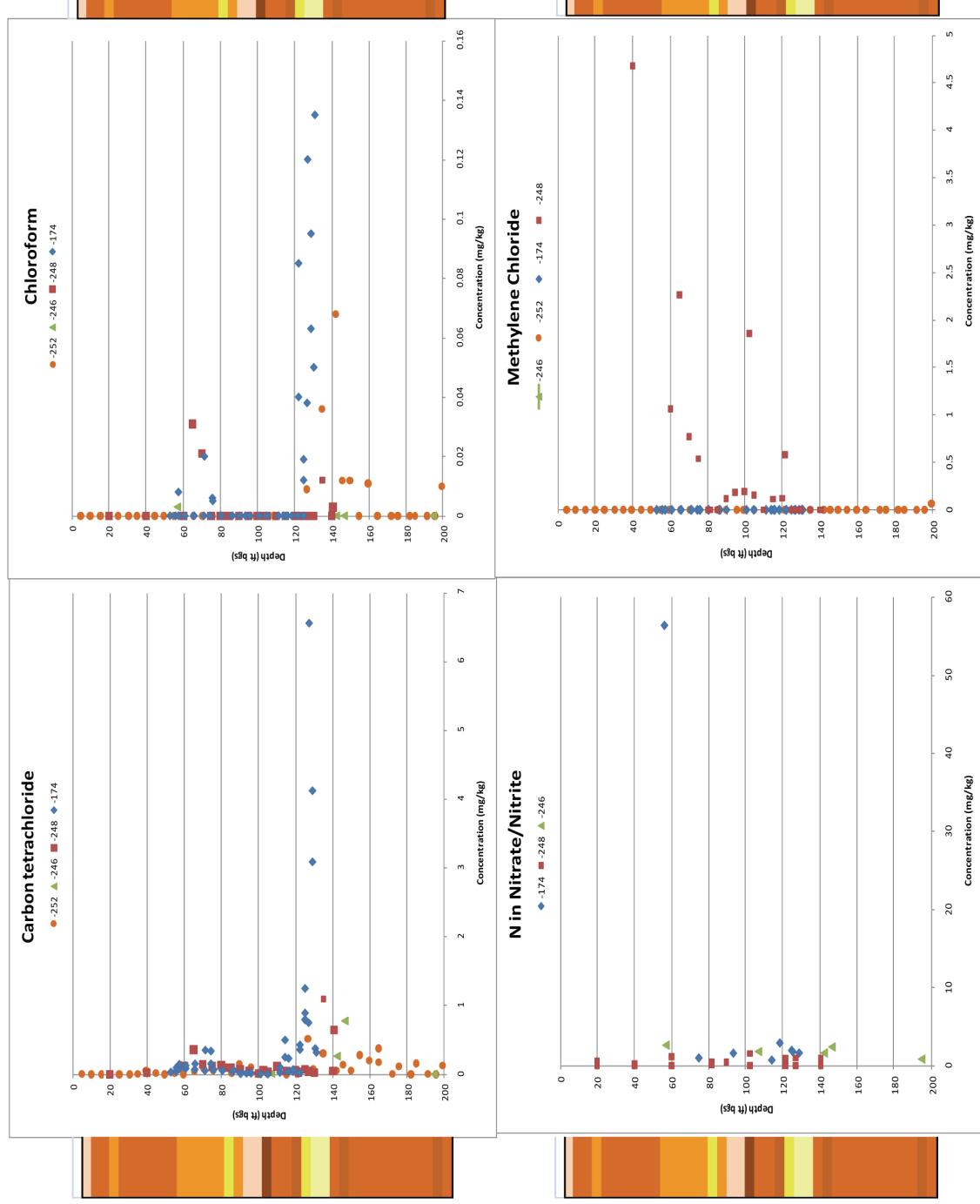


Figure E4-2b. Concentration-Depth Profiles for 216-Z-1A; Based on Stratigraphy from Borehole 299-W18-7

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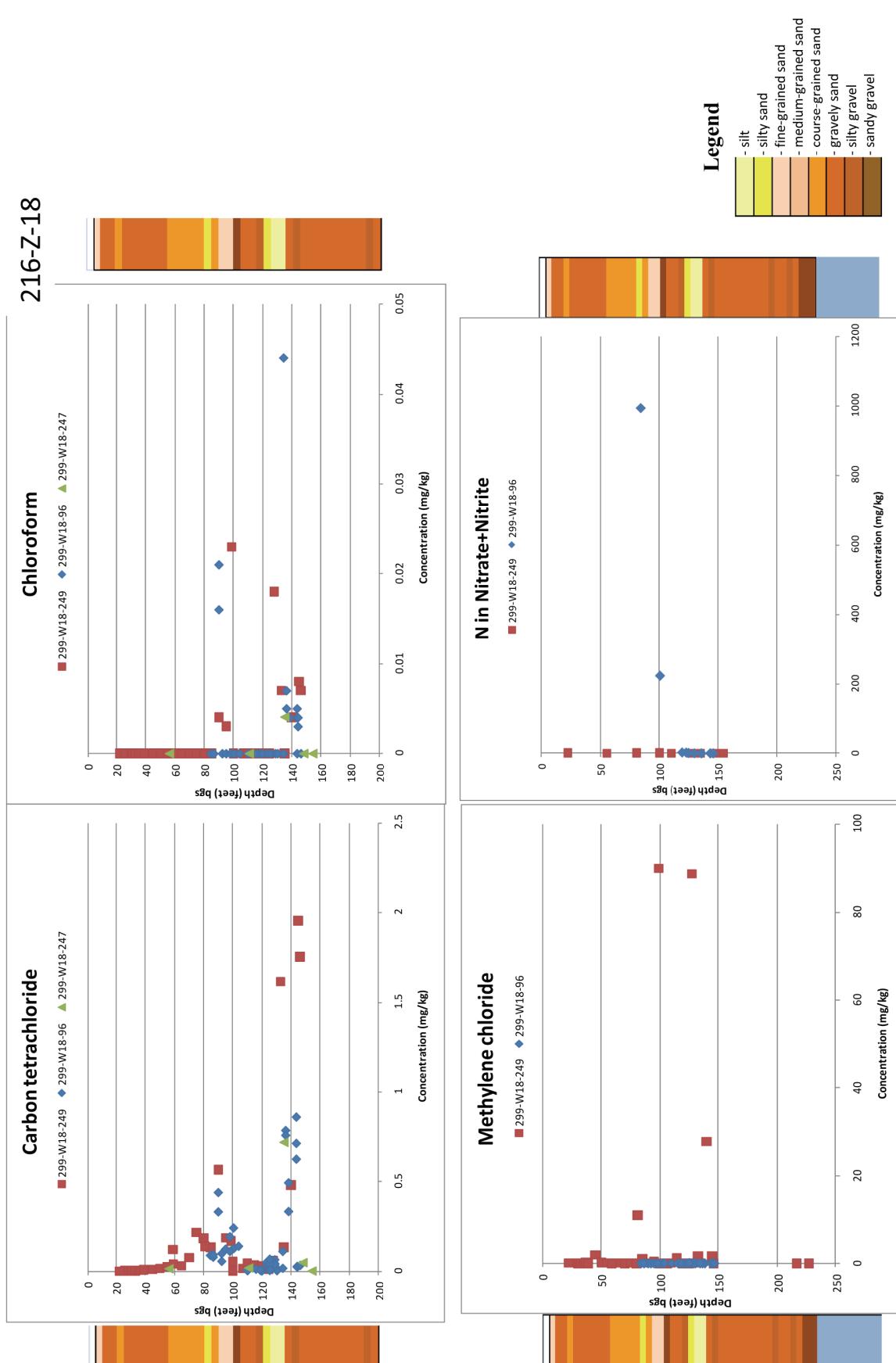
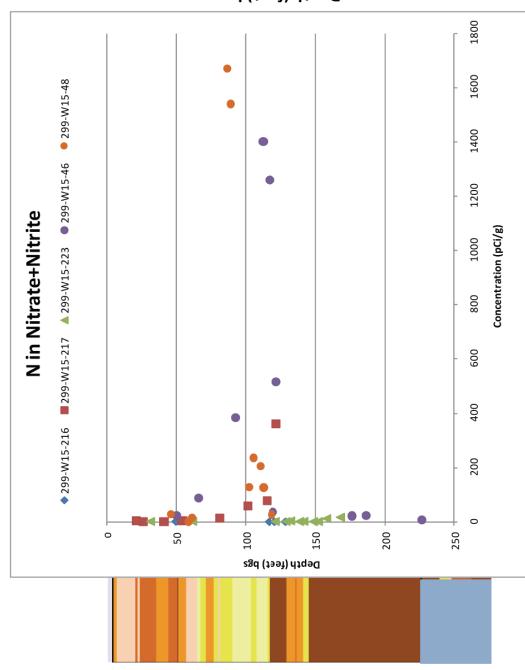


Figure E4-2c. Concentration-Depth Profiles for 216-Z-18; Based on Stratigraphy from Borehole 299-W18-7

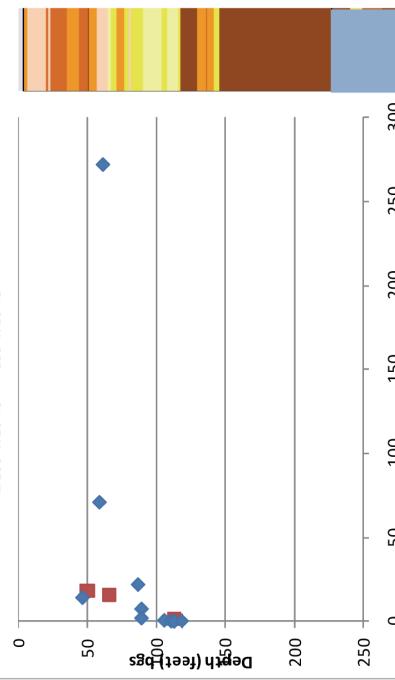
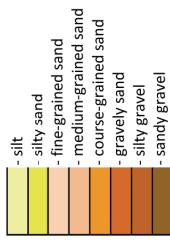
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**Techneium-99 216-Z-9**

■ 299-W15-46

◆ 299-W15-48

◆ 299-W15-46

Legend**Carbon Tet**

■ 1992-93

◆ 2001

▲ 2003

× 2006

Chloroform

■ 1992-93

◆ 2001

▲ 2003

× 2006

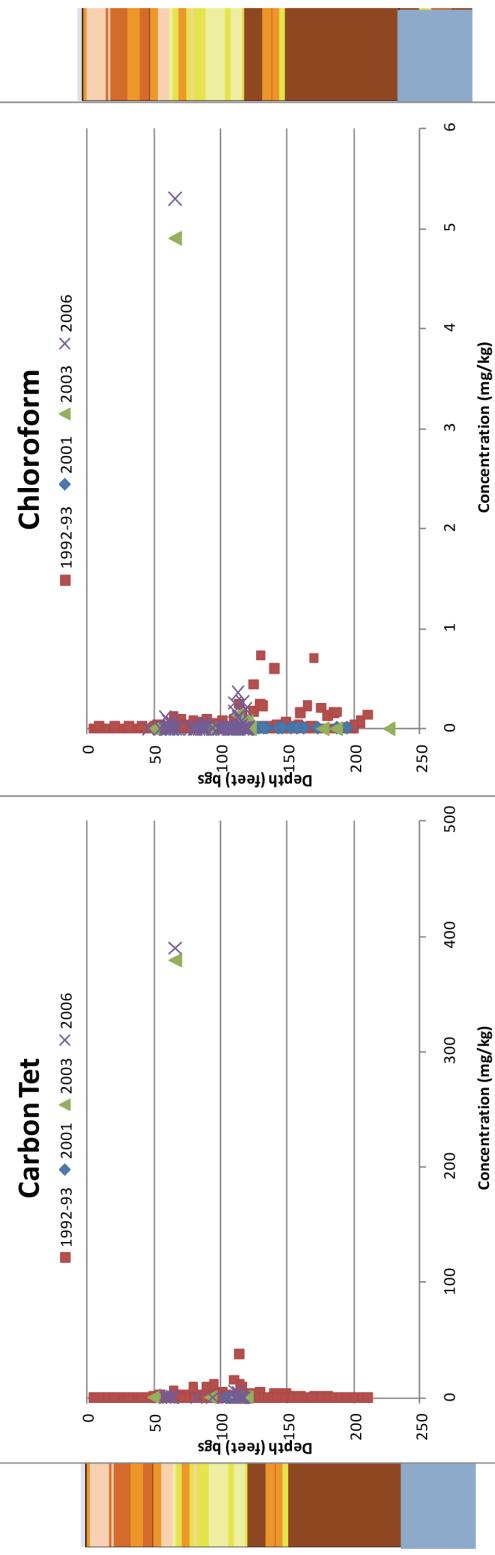


Figure E4-2d. Concentration-Depth Profiles for 216-Z-9; Based on Stratigraphy from Borehole 299-W15-46

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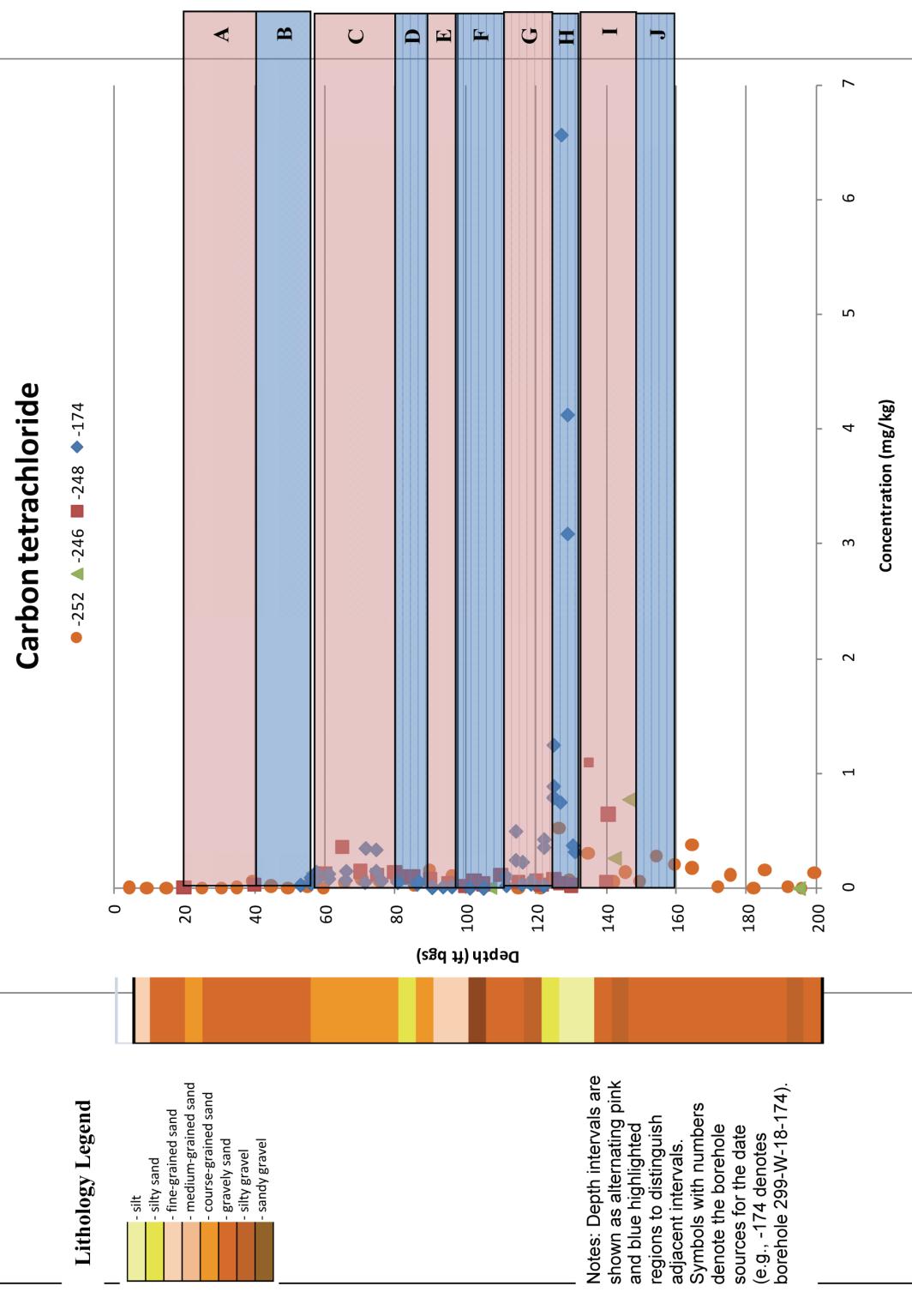
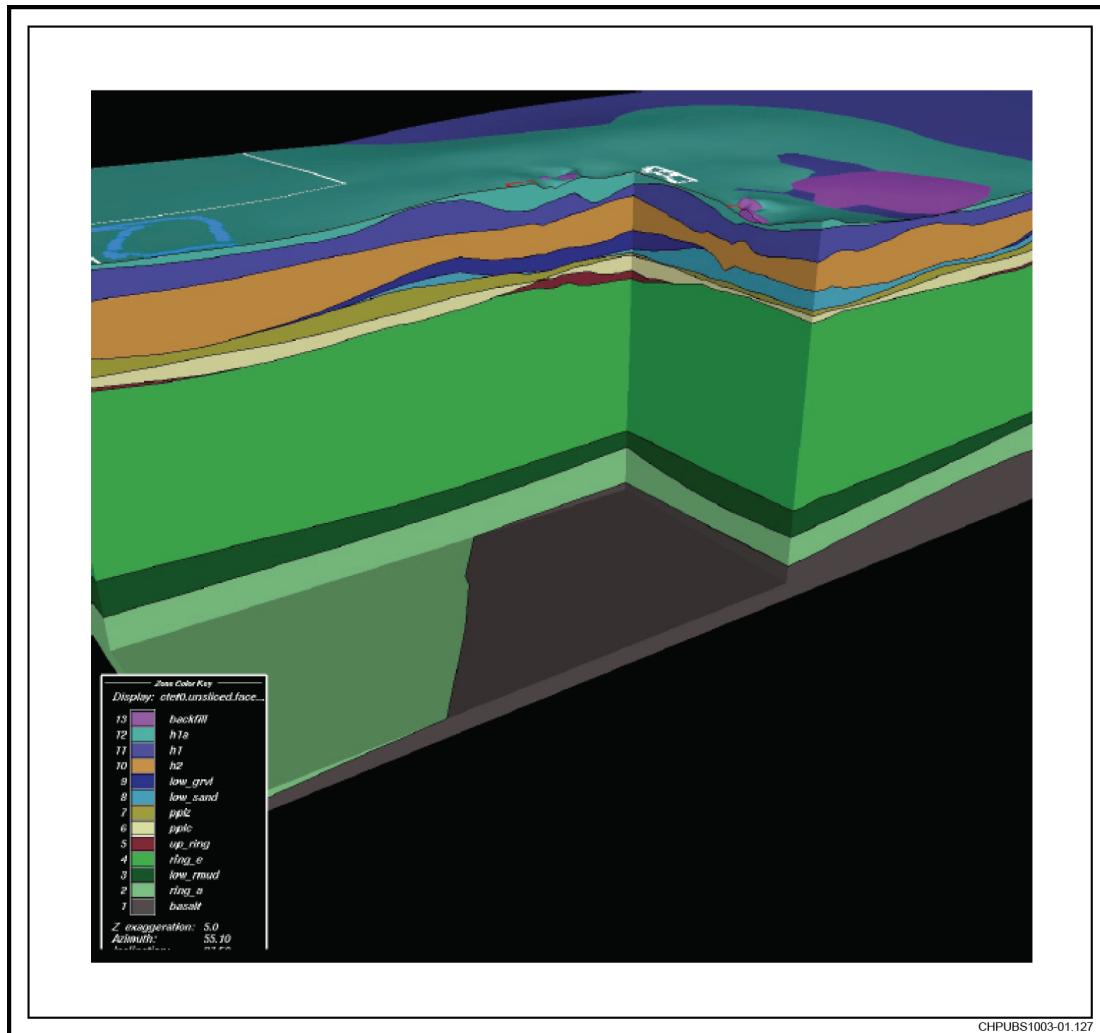


Figure E4-3. Illustration of the Depth Intervals Identified for 216-Z-1A Based on Comparison of the Detailed Stratigraphy and Concentration-Depth Profile for CT



Source: PNNL-14895, *Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site*. Note: for additional information, see PNNL-14895.

Figure E4-4. Three-Dimensional Geologic Model with a Cut-Out Beneath the 216-Z-9 and 216-Z-1A Cribs

The specific stratigraphy used for the vadose zone fate and transport modeling for the 216-Z-9, 216-Z-1A, and 216-Z-18 waste sites shown in Figures E4-5 and Figure E4-6, was based on W-E cross-sections across the domain of each waste site, because the direction of groundwater flow in the unconfined aquifer is primarily west to east in this area. Further description of the stratigraphic units, thicknesses, and hydrogeologic parameters used for these units is provided in ECF-2000PW1-3-6-10-0326.

E4.2.4 Defining Depth Intervals for Contaminated Soil Volumes

Most of the contaminated soil volume assignments for the vadose zone modeling at each of the waste sites can be defined as discrete rectangular-shaped volumes based on the discrete depth intervals identified for the contaminated soil volumes in Section E4.2.2, and appropriate estimates of, or scenarios for, the lateral extent of the contaminated soil volume. However, it was determined that some of the contaminated soil volumes for the waste sites were more appropriately defined differently.

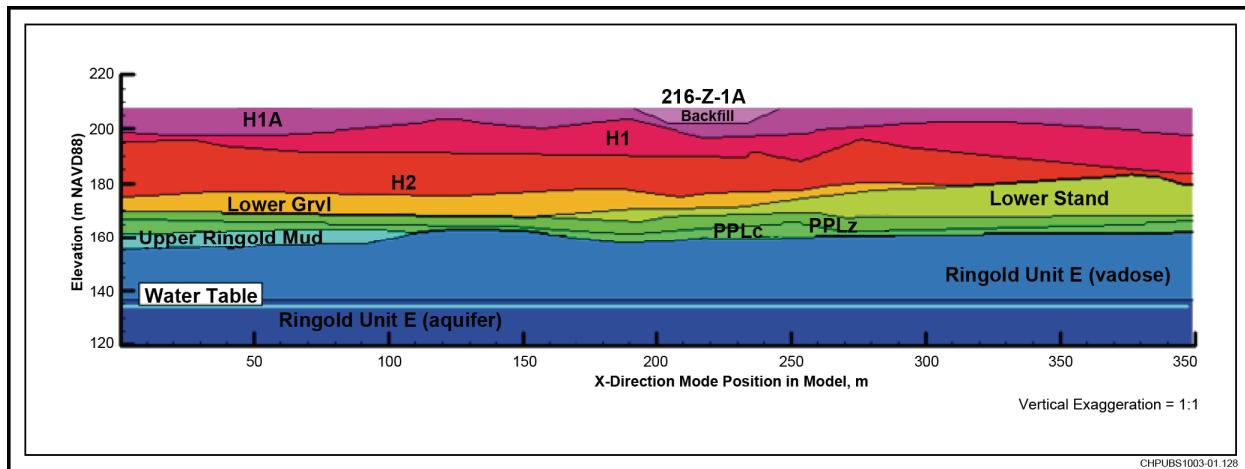


Figure E4-5a

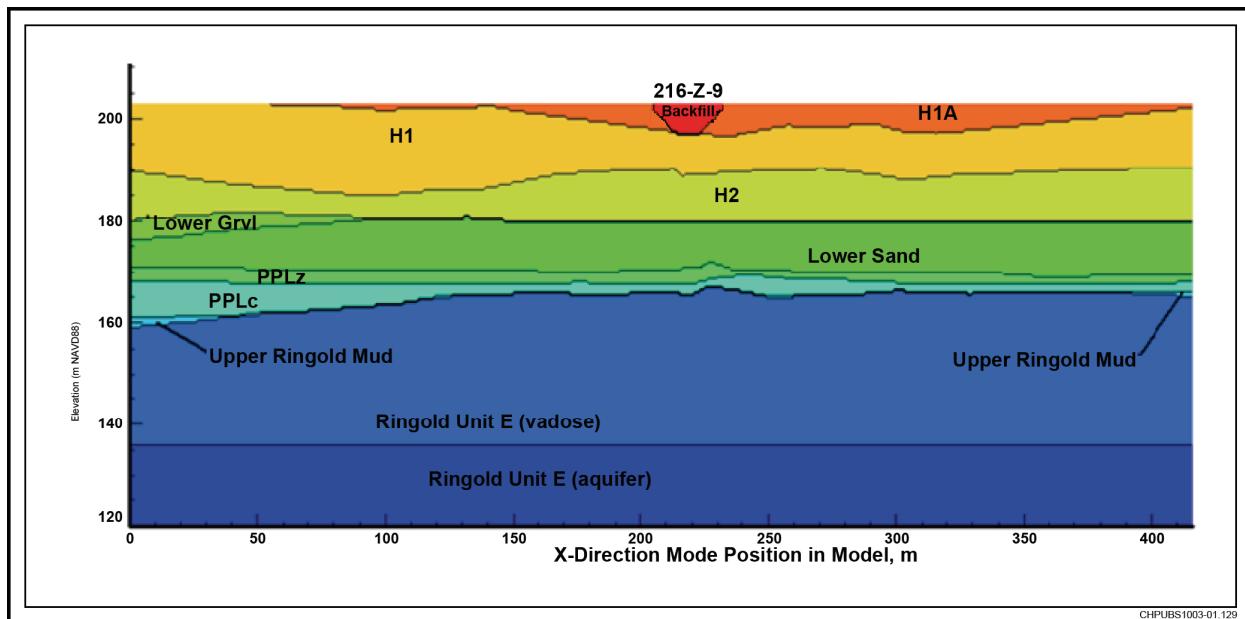


Figure E4-5b

Figure E4-5. E-W Cross-Sections of the Stratigraphy Used in Fate and Transport Modeling of Potential Impacts to Groundwater from Vadose Zone Contaminants at 216-Z-1A and 216-Z-18

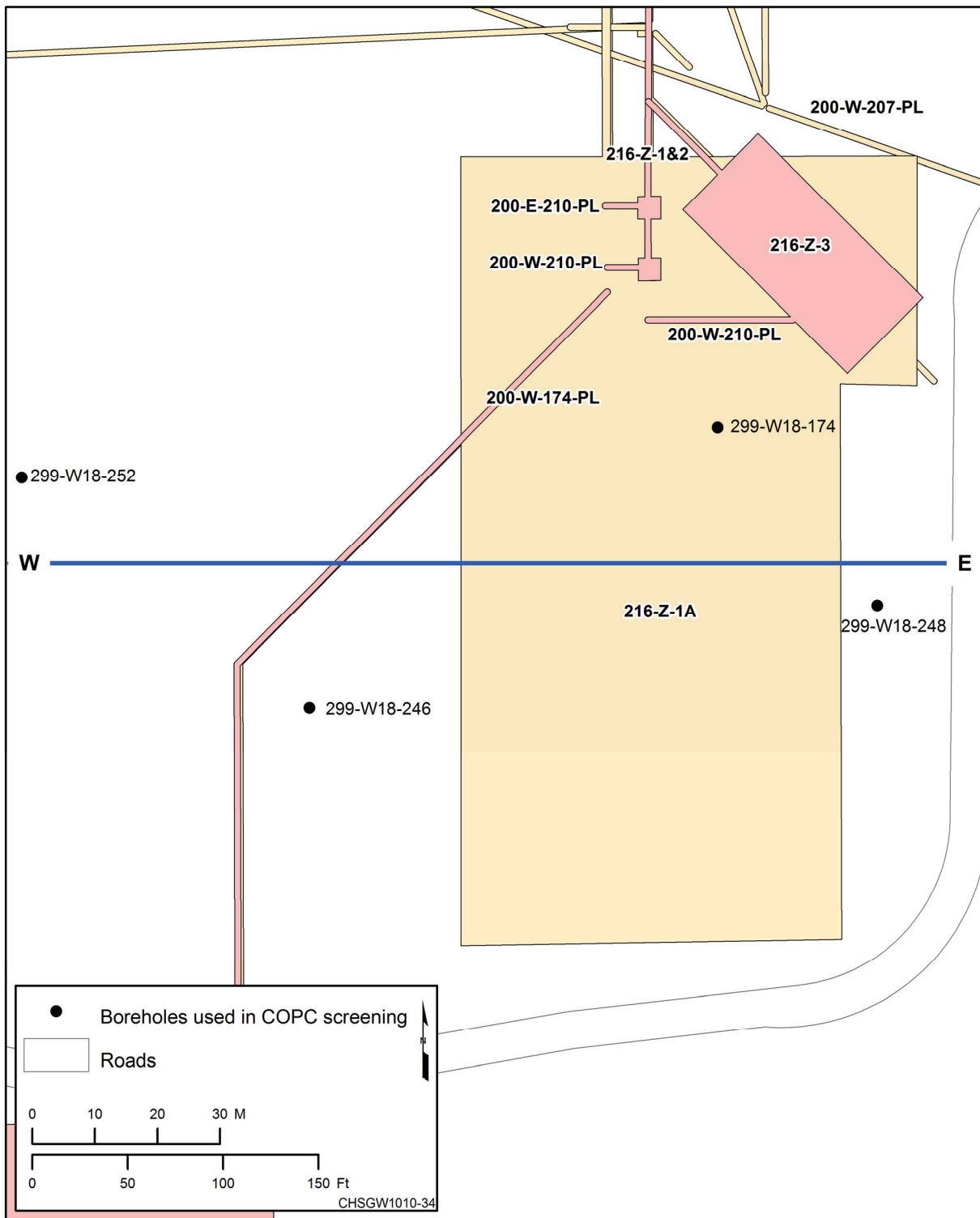


Figure E4-6. Locations of Boreholes and W-E Transect Plane for the 216-Z-1A Crib

Thus, three approaches to defining contaminant source term volumes were used to best represent the vertical distribution of contaminants in the vadose zone in the context of the stratigraphic and lithologic relationships:

1. Contamination volumes defined as a rectangular-shaped volume for a specific depth interval
2. Contamination volumes defined by generally tabular-shaped volumes with variable thicknesses where contamination occurs throughout a geologic unit
3. Contaminated source terms described as unit-thickness volumes, referred to as point source volumes

The first approach for defining contaminated soil volumes is most applicable to contamination residing in lithologic units or intervals that are largely horizontal, which are the conditions for most of the Hanford Site vadose zone sediments. The second approach for defining contaminated soil volumes for modeling is specific to contamination within the Cold Creek unit. Based on evaluation of the COPC concentration depth profiles for the Z-Area waste sites in the 200-West Area shown in Figure E4-2, it is indicated that contamination may largely pervasive throughout much or most of the Cold Creek unit, where the highest levels of contamination also tend to occur. The Cold Creek unit is geologically distinct from the overlying Hanford formation sediments and the underlying Ringold sediments in that it consists of very fine-grained calcareous silty/sandy sediment, calcium-carbonate cemented layers, +/- multi-lithic material in the lowermost part. Although the contamination within the Cold Creek unit is consistent with the contaminant behavior conceptual model, in that contamination tends to occur preferentially in lithologies containing finer-grained and/or calcareous sedimentary material, a different definition of the geometry of the contaminated soil volume represented by the Cold Creek unit was deemed to be appropriate. Therefore, the contaminated soil volumes for the upper and lower facies of the Cold Creek formation in the vadose zone beneath the 216-Z-9, 216-Z-1A, and 216-Z-18 Cribs were determined using the variable thickness of the Cold Creek unit based on the detailed description of the Cold Creek unit in the geologic framework determined in the studies by Pacific Northwest National Laboratory (PNNL) (PNNL-14895; PNNL-15914; PNNL-16198).

Contaminated soil volumes defined as point source (1 m [3 ft] thickness) volumes were determined to be warranted where the sampling results indicated that the contamination occurred essentially at an isolated depth, where there are one or more data points at given depth, not part of a data series related to a lithologic layer or unit. Therefore, point source volumes were defined based on an assumed thickness of 1 m (3.2 ft). Depth intervals of 1 m (3.2 ft) were used for the 216-A-8 waste site, and for the uppermost source term (<7.5 m [<24.5 ft] bgs) at 216-Z-9 where there were only one or three data points at a specific depths for multiple COPCs. Thus, the entire source term was assumed to reside in a 1 m (3.2 ft) thick layer at each of the depths specified in Table E4-1. The depth of the top or bottom of a contaminated soil thickness interval was adjusted slightly in some cases to accommodate the modeling grid spacing.

Table E4-1 summarizes the specific depth intervals of contaminated soils identified for the 216-A-8, 216-Z-1A, 216-Z-18, and 216-Z-9 waste sites. An example of the depth intervals used 216-Z-1A are shown together with the concentration-depth profile for CT and the stratigraphic relationships in Figure E4-3 to illustrate the manner in which data were grouped for the depth intervals. These depth intervals for the waste sites are also illustrate in Figure E4-6 together with the lateral dimensions for the modeling base case.

Table E4-1. Summary of the Depth Intervals of Contaminated Soils for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Waste Sites

216-Z-1A & 216-Z-18 Contaminated Soil Depth Interval; Top to Bottom				216-Z-9 Contaminated Soil Depth Interval; Top to Bottom				216-A-8 Contaminated Soil Depth Interval; Top to Bottom				
Interval ID	Depth bgs (ft)	Thickness (m)	Depth bgs (ft)	Interval ID	Depth bgs (ft)	Thickness (m)	Depth bgs (ft)	Interval ID	Depth bgs (ft)	Thickness (m)	Thickness (m)	
A	20-40	6-12.2	20	7	1	<24.5	<7.5	1	A	19-21.5	5.8-6.4	2.5
B	40.5-56	12.3-17.1	15.5	5	2	31-45	9.5-13.7	4	B	22.5-25	6.8-7.6	2.5
C	57-80	17.3-24.4	23	6	3	46-50	14-15.2	4	C	27.5-30	8.4-9.1	2.5
D	80.5-90	24.5-27.4	9.5	3	4	54-60	16.5-18.3	6	D	104-106.5	31.7-32.5	2.5
E	90.1-96	27.5-29.3	5.6	2	5	61-67	18.6-20.4	6				1
F	98-111.5	29.9-34	12	4	6	67-82	20.4-25	15				
G	111.5-122.5	34-37.3	12	4	7	87-93	26.5-28.3	6				
H	123-130.5	37.5-39.8	5.5	2	8	94-102	28.6-31	6				
I	131-146	39.9-44.5	PPLZ	3.5-5	9	102-106	31-32.3	4				
J	146.1-160	44.5-48.7	PPLC	2-5.5	10	111-118	33.8-36	PPLZ	1-3.5			
				11	118-123	36-37.5	PPLC	1-4				
				12	123-130	37.5-39.6		7	2			
				13	133-140	40.5-42.7		7	2			
				14	177-186	54-56.7		6	2			
				15	190-195	58-59.4		5	2			

E4.3 Estimation of the Lateral Extent of Contaminated Soil Volumes

The contaminated soil volumes that together with representative COPC concentrations serve as the basis for defining the source term masses in fate and transport modeling used in the assessment of impacts to groundwater. The volume estimates depend on a determination of representative, and/or upper bound limits for the lateral extent of contamination in the vadose zone beneath the 200-PW-1/3/6 waste sites parallel to the direction of groundwater flow. Evaluations of the lateral extent of contamination at the 216-Z-1A and 216-Z-9 waste sites were primarily based on the following lines of evidence:

1. Contaminant concentration patterns observed for transects across the waste sites, extending beyond the waste site boundaries
2. Evaluation of isopleth (contours) depictions of COPC soil concentrations beneath the waste sites
3. Three-dimensional depictions of the lateral and vertical extent contamination at the waste sites
4. A comparison and contrast of these lines of evidence with 3-D modeling of CT behavior in the vadose zone
5. Consideration of other relevant information

The types of other relevant information considered in this evaluation include the following:

1. Site data and model results on the lateral extent of CT dense, nonaqueous-phase liquid (DNAPL) contamination
2. The physical and chemical properties of the COPCs at the 216-Z-1A and 216-Z-9 waste sites
3. Comparison of COPC data and subsurface concentration contours before and after implementation of the SVE system in 1992 to 1993
4. The nature and extent of plutonium (transuranic) contamination in the vadose zone
5. The spatial distribution of contamination observed at other Hanford waste sites with comparable/analogous liquid disposal volume histories

Selected COPC data from boreholes within, and/or extending outward from the 216-Z-1A and 216-Z-9 waste sites boundaries were evaluated in these various ways to determine the lateral extent to which contamination in the subsurface extends outward from the vicinity of the waste sites. These data enabled the lateral extent of the overall contamination to be evaluated, and enabled the lateral extent of contamination within discrete geologic intervals to be evaluated as a function of depth and over time. The data associated with the 216-Z-1A and 216-Z-9 waste sites are especially conducive to these types of methods to evaluate the lateral extent of contamination because of the number, locations, and chronology of borehole data in and around the waste sites (see Figures E4-6 and E4-8). The nature and extent of contamination associated with these waste sites is considered to be representative for the 200-PW-1/6 waste sites in the Z-Area. The extent of contamination at these waste sites is also likely to serve as an analogue and/or bounding example for contaminant behavior at other Hanford wastes sites in the context of the type and magnitude of liquid discharges received. These cases are also considered here to be representative and/or bounding for the 216-Z-18 and 216-A-8 waste sites where less characterization borehole and subsurface data are available.

E4.3.1 Contaminant Profile Transects

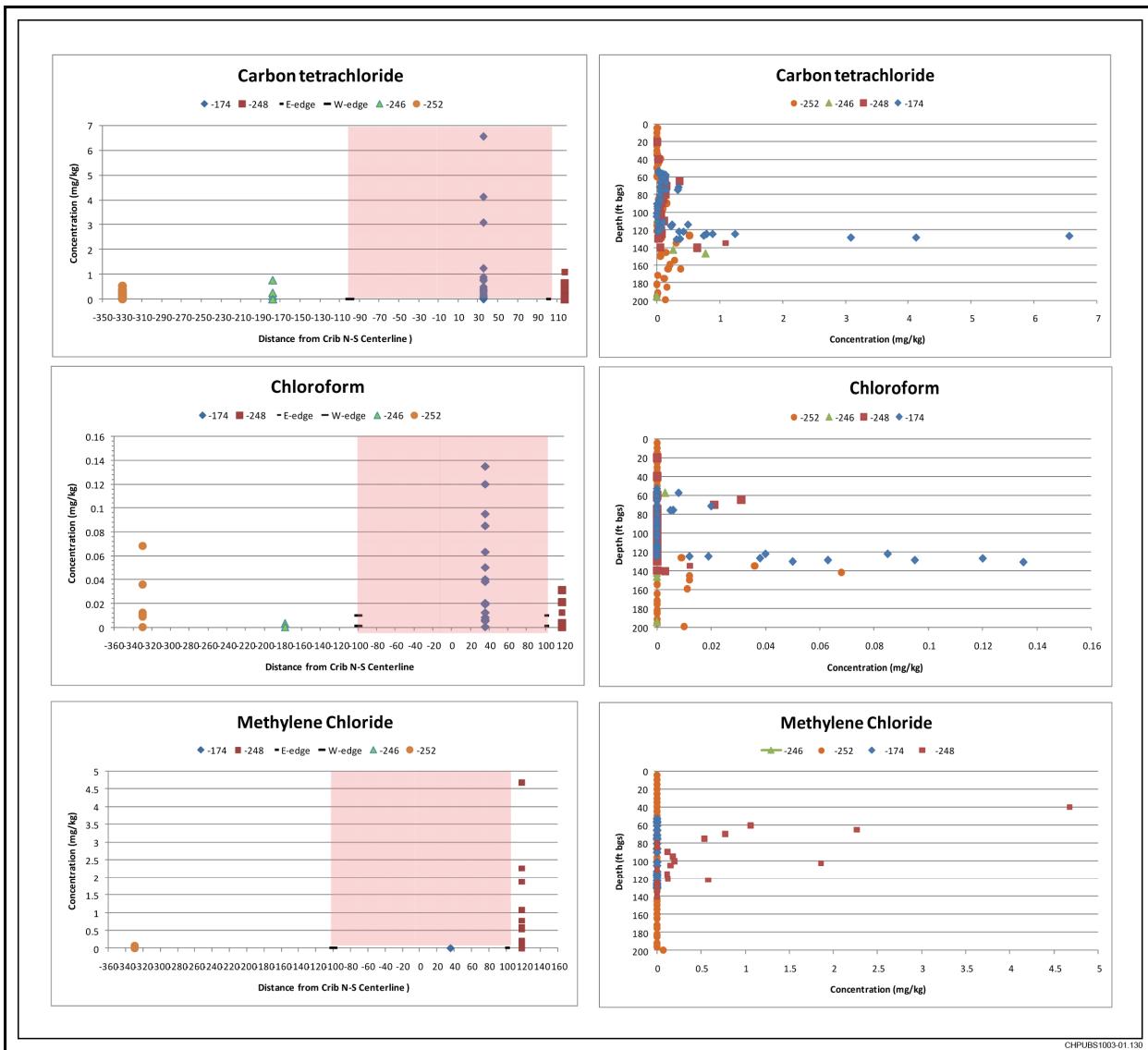
The contaminant profile transects were constructed by plotting the soil concentrations of selected COPCs (y-axis) against the distance from the centerline of the crib, as projected onto a vertical plane (transect) extending through the crib in a west-east (W-E) direction (the direction of groundwater flow), and the length dimension used in the fate and transport modeling (as shown in the following sections). These transects were also evaluated in the context of the COPC concentration depth profiles to show the depths at which the highest concentrations occur in the context of the waste site footprint. Additional transects were also evaluated for the data from the 216-Z-9 crib, which included transects in an N-S direction through the crib, and lateral W-to-E transects at the north and south edges of the crib.

E4.3.2 216-Z-1A Transect and Depth Profiles

Representative data for the most frequently detected COPC analytes measured in each of four boreholes transecting the 216-Z-1A waste site in an E-W direction shown in Figures E4-7a and E4-7b, were evaluated in the context of: (a) overall concentrations in the E-W transect, and (b) depth profiles for each borehole. The COPC analytes chosen for evaluation in the contaminant profile transects were COPCs passing all screening steps, and which were measured in each of the boreholes. These analytes include CT, chloroform, methylene chloride, tetrachloroethene, trichloroethene, and nitrogen (nitrate+nitrite). All of the data for the representative COPCS are plotted in Figures E4-7a and E4-7b, by distance from the centerline of the crib. The relative location of the crib in the transects are shown in Figures E4-7a and E4-7b as the highlighted (pink) regions in the transect Figures.

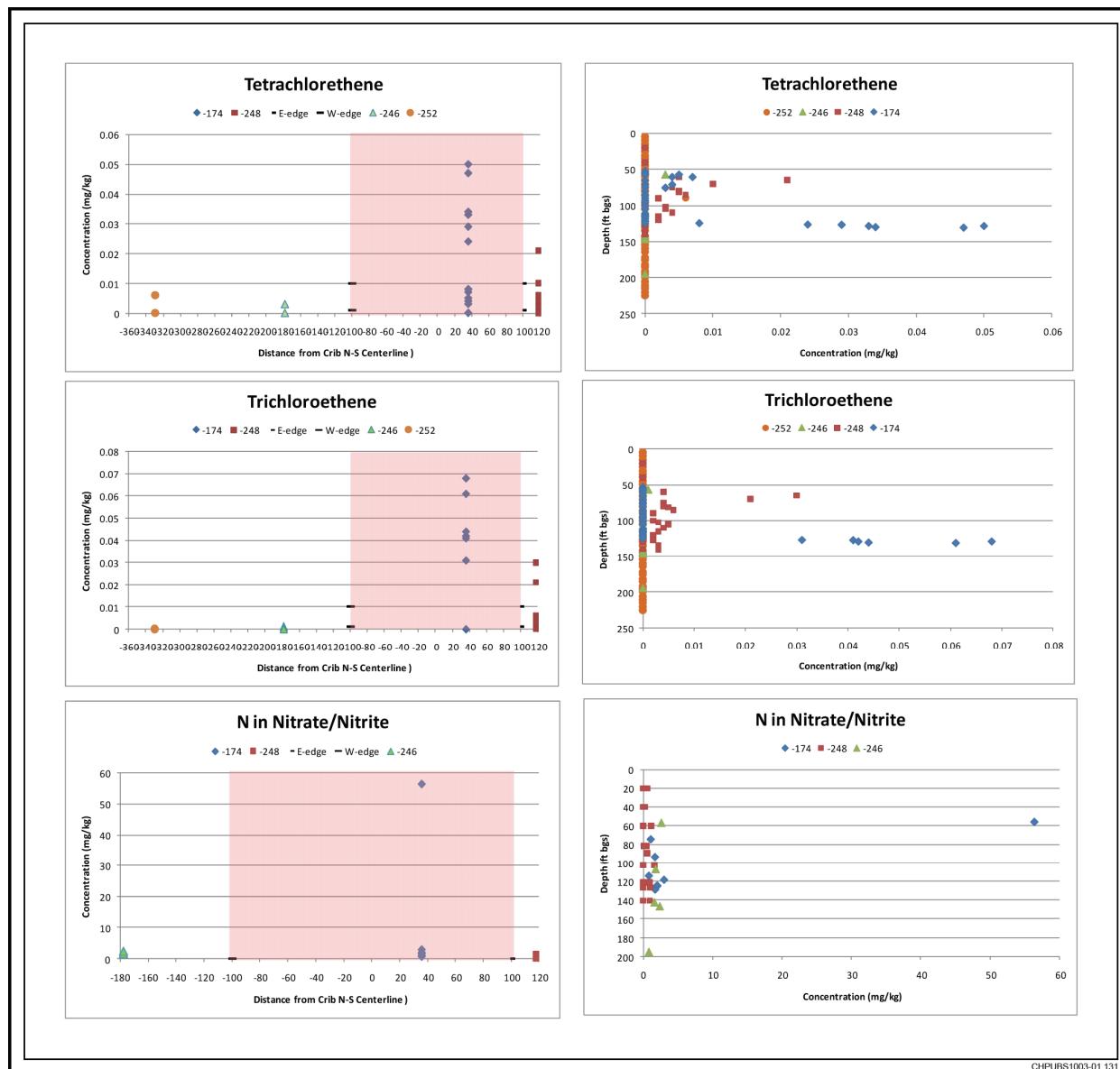
It is indicated from the comparison of the representative COPC data in the W-E transects across the 216-Z-1A waste site, that for all but one of the COPCs (methylene chloride), the maximum contamination levels are largest beneath the waste site footprint, and decrease sharply to significantly smaller levels outside the footprint of the waste site. The lateral and vertical distribution for all of the volatile organic COPCs, except for methylene chloride, follows the same pattern, and appears to be strongly correlated. The levels of nitrogen in nitrate+nitrite in all but one sample are below natural background levels. The one sample with an elevated nitrogen level (approximately 58 mg/kg) occurs beneath the waste site footprint at a depth of about 18 m (60 ft) bgs. The following is a summary of the most notable subsurface spatial patterns of COPC soil concentrations resulting from the evaluation of the transects and depth-concentration profiles:

1. There are relatively few data with very high levels of contamination.
2. The highest levels of contamination are generally beneath the footprint of the waste site and do not extend laterally beyond the E-W margins of the waste site (footprint).
3. The highest levels of contamination beneath the waste site, and on the flanks, occur in the Cold Creek sediments (approximately 32 to 38 m [105 to 125 ft] bgs) and/or in the contaminated interval from about 18 to 24 m (60 to 80 ft) bgs.
4. Intermediate levels of contamination in the Cold Creek formation, and/or, within the contaminated interval from about 18 to 24 m (60 to 80 ft) bgs do extend beyond the east and west boundaries of the waste site for VOA COPCs.



Notes: The location of the Crib footprint in the transects is depicted as the pink shaded areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-7a. Lateral Patterns of Soil Concentrations for CT, Chloroform, and Methylene Chloride with Respect to Distance from the 216-Z-1A Crib Footprint in a W-E Transect Through the Waste Site



Notes: The location of the Crib footprint in the transects is depicted as the shaded (pink) areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-7b. Lateral Patterns of Soil Concentrations for Tetrachloroethane, Trichloroethene, and Nitrogen in Nitrate+Nitrite with Respect to Distance from the 216-Z-1A Crib Footprint in a W-E Transect Through the Waste Site

The only exception to these patterns of contaminant behavior are the levels of methylene chloride in samples from borehole 299-W18-248 which appear to be spurious, rather than representative of the actual nature and extend of the contamination in the vadose zone. These data appear to be spurious because the largest levels occur in samples from the borehole east of the crib, rather than beneath the crib and, therefore, do not correlate with any of the behavior of any of the other volatile COPCs seen at other waste sites. The absence of any measurable methylene chloride from the vadose zone soils directly beneath the waste site where the maximum values of all other COPCs is also indicative of spurious data. This hypothesis is consistent with the occurrence of methylene chloride as a common laboratory contaminant in the reagents used in laboratory glassware cleaning.

All of the COPC data evaluated for the 216-Z-1A and the 216-Z-18 waste sites were collected in 1992 to 1993, prior to, or just following startup of the SVE system that has been in operation since 1992 to 1993. The vintage of these data are important because the levels of the VOAs in the vadose zone soils have been significantly reduced, as indicated from the data obtained from 216-Z-9 (Sections E4.3.1 to E4.3.3). Although these are the only data available from the 216-Z-1A waste site, these data are regarded as conservatively biased, as discussed in the sections on modeling results and uncertainties (Section E4.4).

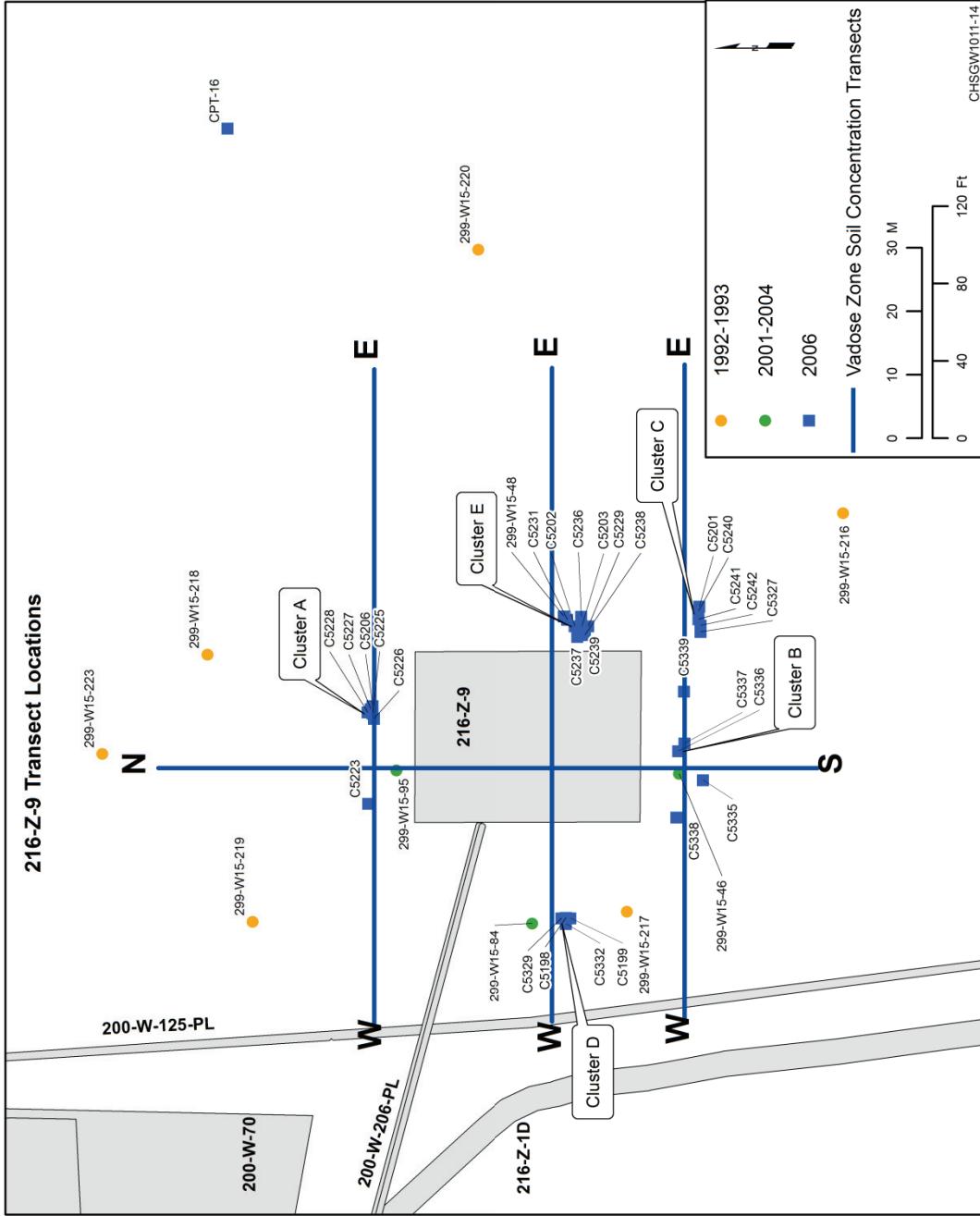
E4.3.3 216-Z-9 Transect and Soil Concentration Depth Profiles

Transects and depth profiles for the 216-Z-9 Crib were evaluated based on data for representative COPCs from 41 boreholes and/or subsurface sampling locations surrounding the 216-Z-9 waste site.

Four transects and associated COPC depth profiles were used to determine and constrain the extent of the contamination laterally and vertically in the vadose zone beneath the 216-Z-9 waste site (Figures E4-9a through E4-9f). Data for CT, chloroform, methylene chloride, tetrachloroethene, hexachloroethane, and nitrogen in nitrate+nitrite were evaluated in the 216-Z-9 transects and depth profiles.

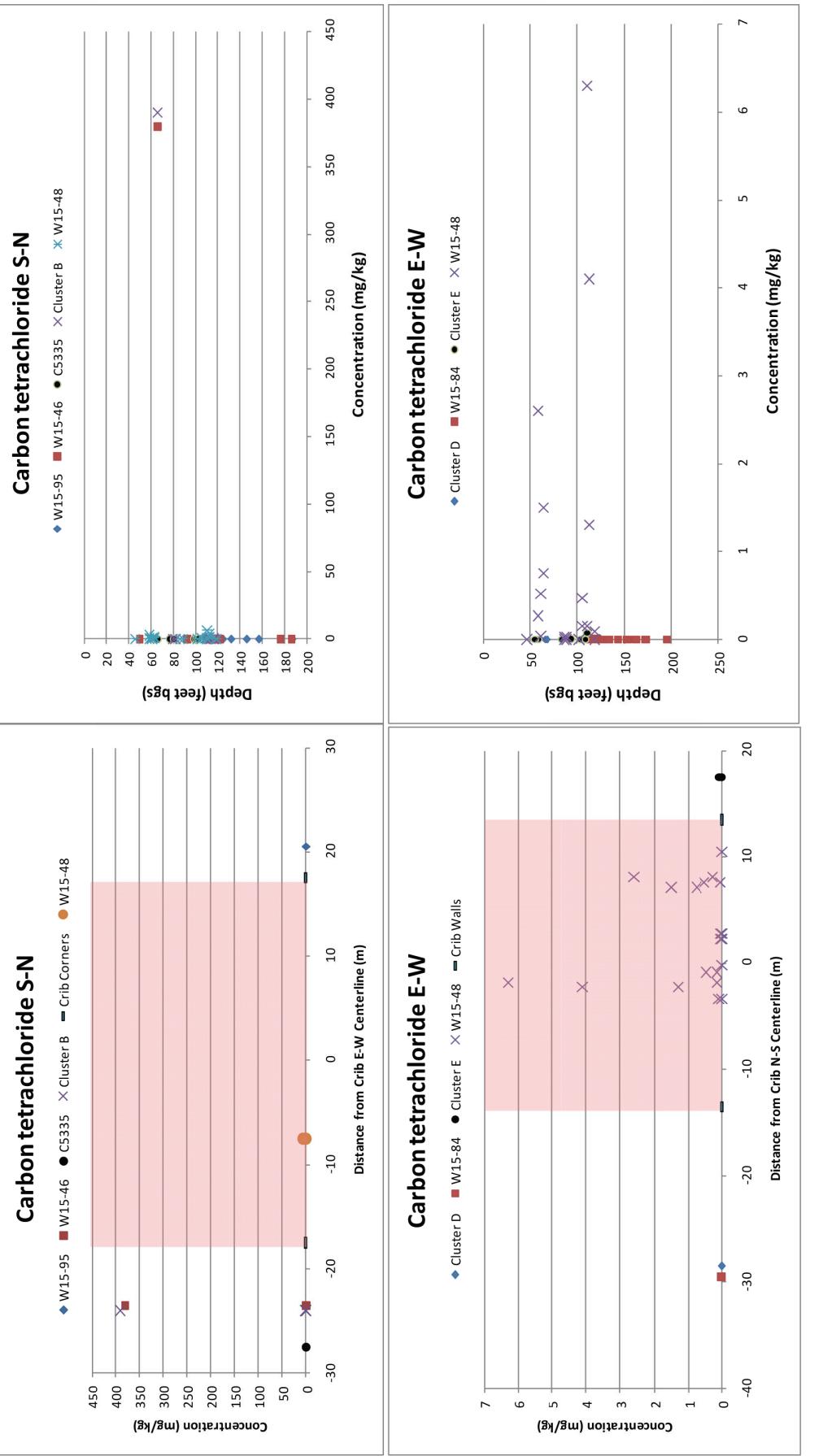
Data from six boreholes were evaluated in the construction of an N-S transect across the waste site (Figure E4-8). Three W-E transects were also evaluated; one through the center of the waste site, one approximately 10 m (33 ft) from the north edge of the waste site, and a third, approximately 10 m (33 ft) from the south edge of the waste site. Data from two boreholes, a clusters of five borings, and a second cluster of eight boring were evaluated in the E-W transect through the center of the waste site (Figure E4-9.). Data from eight boreholes or borings were used in the construction of the W-E transect at the north end of the 216-Z-9 crib (Figure E4-10). A total of 3 boreholes and 12 borings (two clusters of 5 and 7 borings, respectively) were used in the construction of the W-E transect at the south end of the 216-Z-9 crib (Figure E4-10). The transect data are shown in Figures E4-9 to E4-10, by distance from specified reference locations, e.g., the N-S centerline for W-E transect, and the W-E centerline for the N-S transect. The relative positions of the crib footprint boundaries are also shown as highlighted rectangles in the Figures. Depth profiles, i.e., COPC concentration with depth, for each transect data set are also shown in these Figures. The transect data together with the depth profile data provide a basis for evaluating the lateral and vertical extent of subsurface contamination at the 216-Z-9 Crib.

The COPC concentrations were also evaluated in the context of the chronology of the sample data. The data from the 41 boreholes near the 216-Z-9 crib represent four time intervals: data collected in 1992 to 1993, 2001, 2004, and 2006. The dates of the data are important because a majority of the COPCs passing all phases of the screening and evaluation are VOCs that would be affected by the operation of the SVE system initiated in 1992 to 1993. Thus, the data from 1992 to 1993 represent the soil concentrations at the beginning of the SVE operation; the data from 2001, represent concentrations after about 7 to 8 years of SVE operation; and the data from 2006, represent concentrations after about 14 years of SVE operation. The trends of COPC concentrations for these periods are also shown in the transects and depth profile data discussed and shown in Section E4.3.2 (Figures E4-9 and E4-10). The COPC data used in the construction of the transects for the VOA COPCs omitted the older 1992 to 1993 data as less representative of the current contaminant conditions than the more recent data collected from 2001 to 2006. However, all data were used in the construction of the transects and depth profiles for nitrogen in nitrate+nitrite because this COPC is not expected to be affected by the SVE operation. Thus, all of the nitrate/nitrite data can be used to delineate the spatial extent of contamination.



Notes: The data for the N-S and E-W transects across the waste site are labeled as N-S and E-W, respectively, in Figure E4-9. The data for the W-E transects adjacent to the north and south boundaries of the Crib are labeled as N-E-W and S-E-V, respectively, in Figure E4-10.

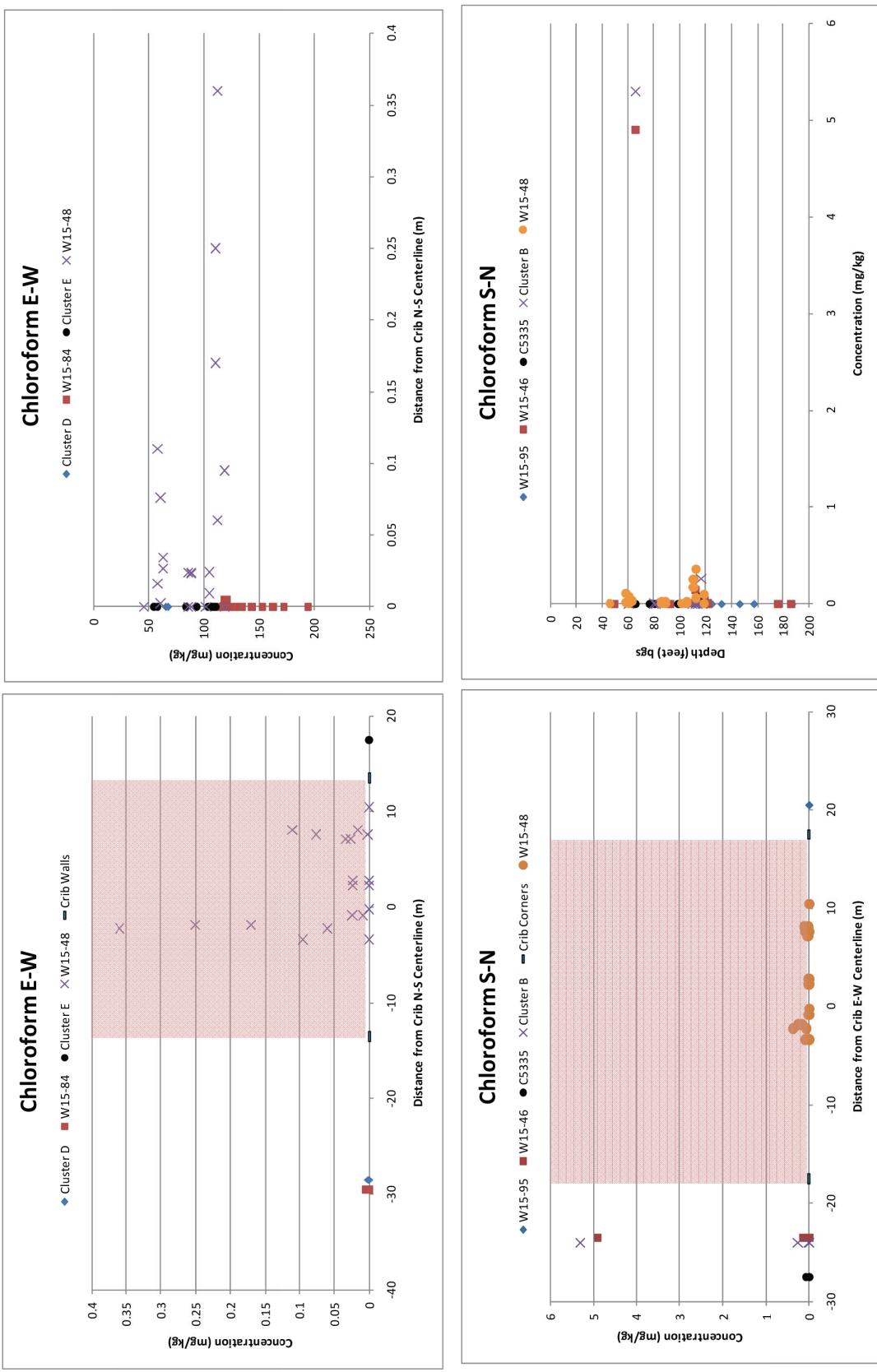
Figure E4-8. Locations of Vadose Zone Soil Concentration Transects Across and Adjacent to the 216-Z-9 Crib



CHPUBS103.01.132

Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

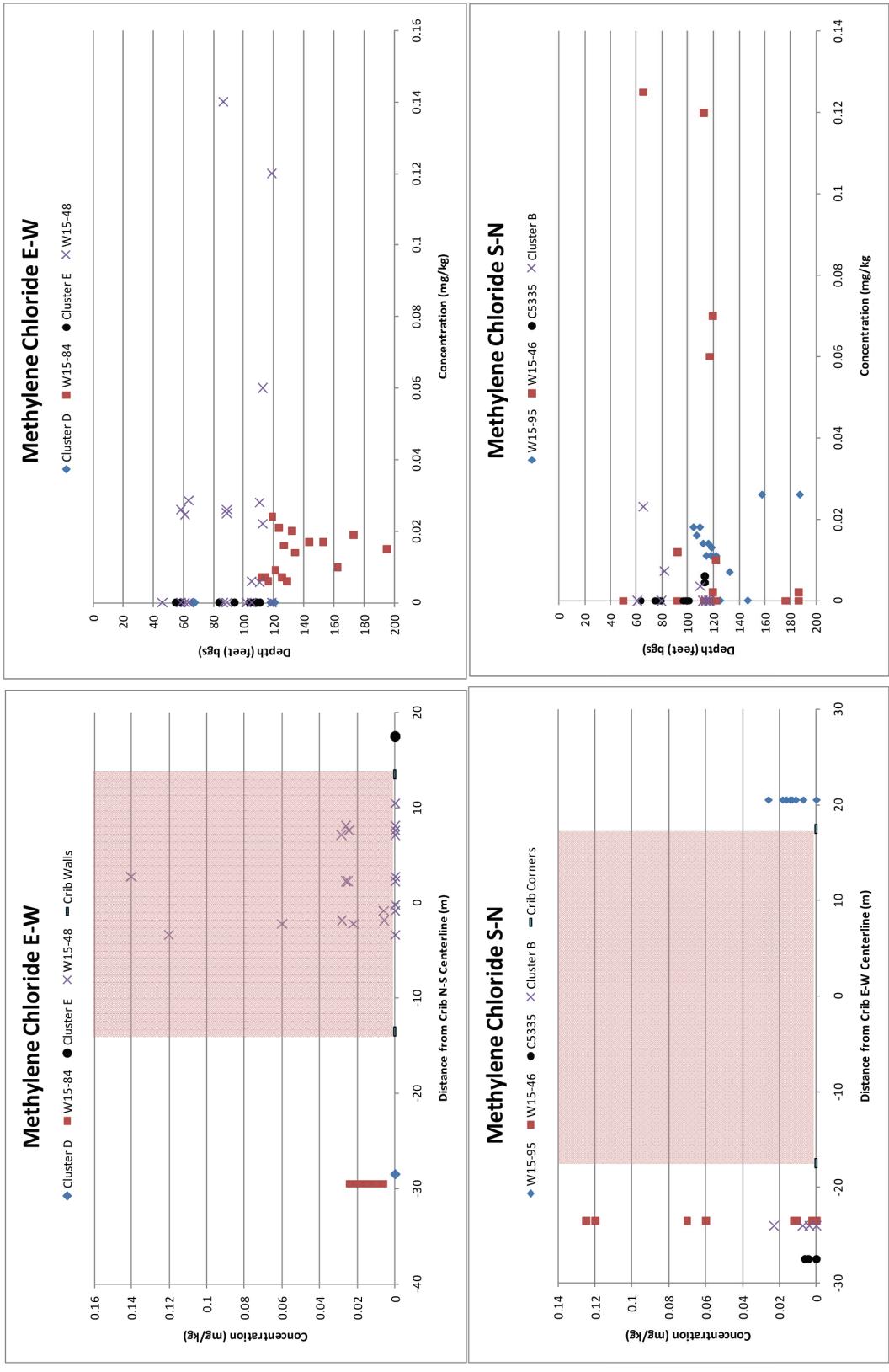
Figure E4-9a. Lateral Patterns of Vadose Zone Soil Concentrations for CT with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site



Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

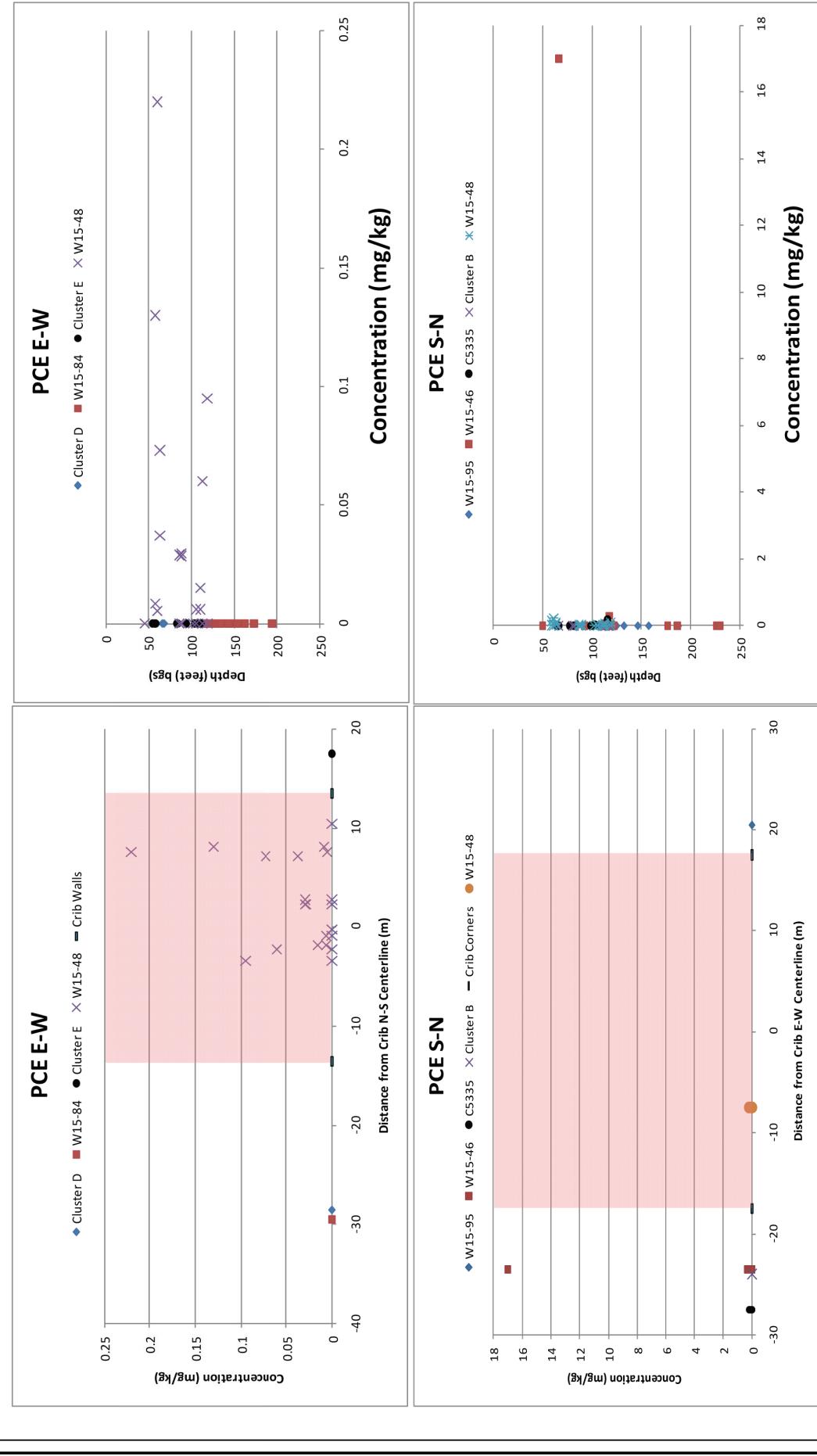
Figure E4-9b. Lateral Patterns of Vadose Zone Soil Concentrations for Chloroform with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site

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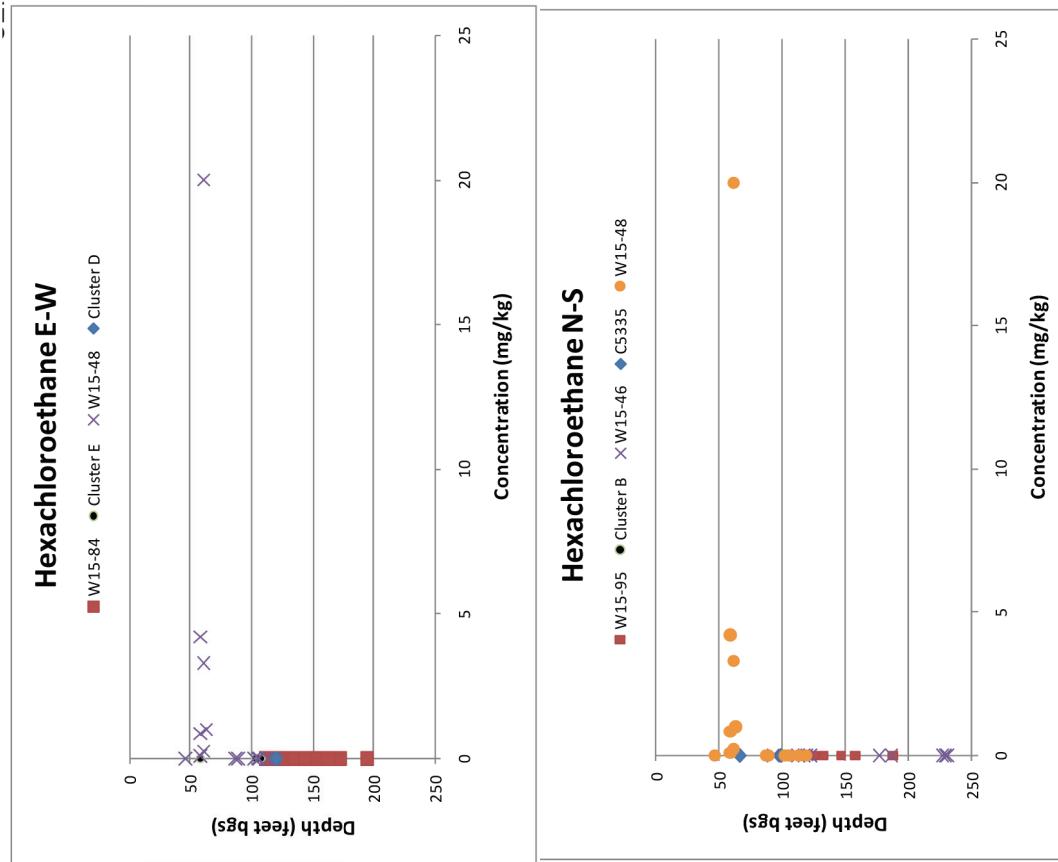
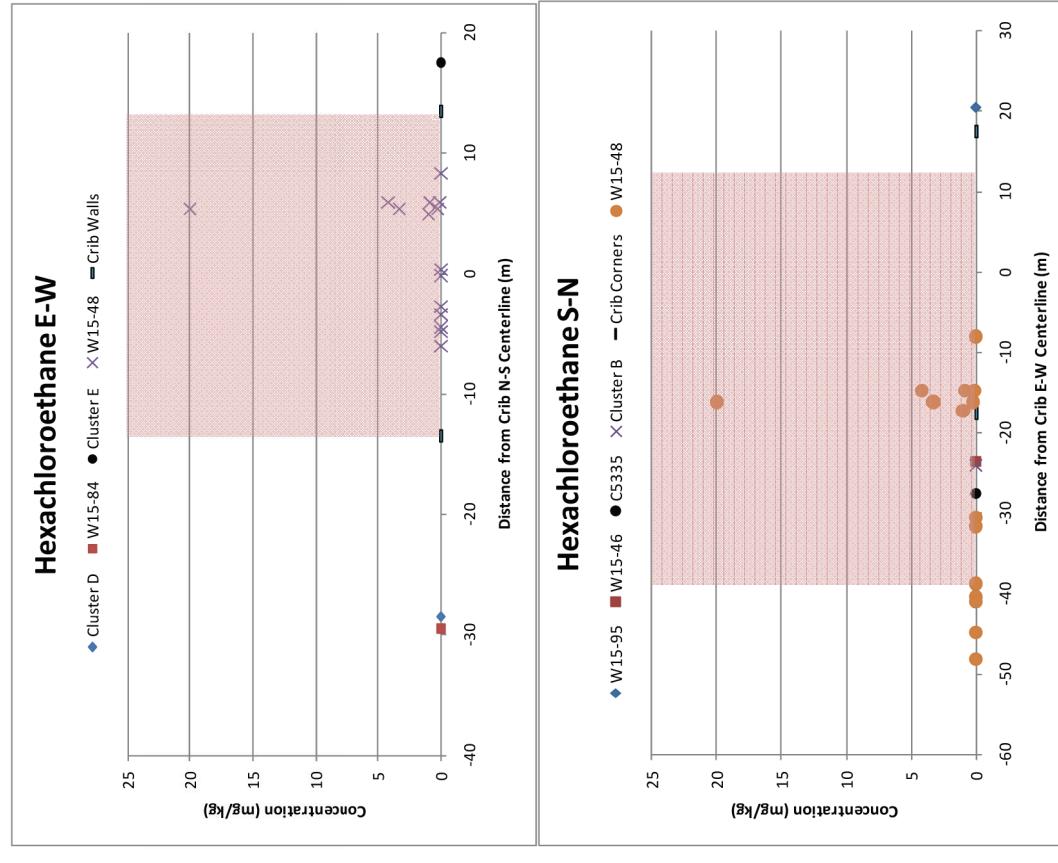
Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-9c. Lateral Patterns of Vadose Zone Soil Concentrations for Methylene Chloride with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site



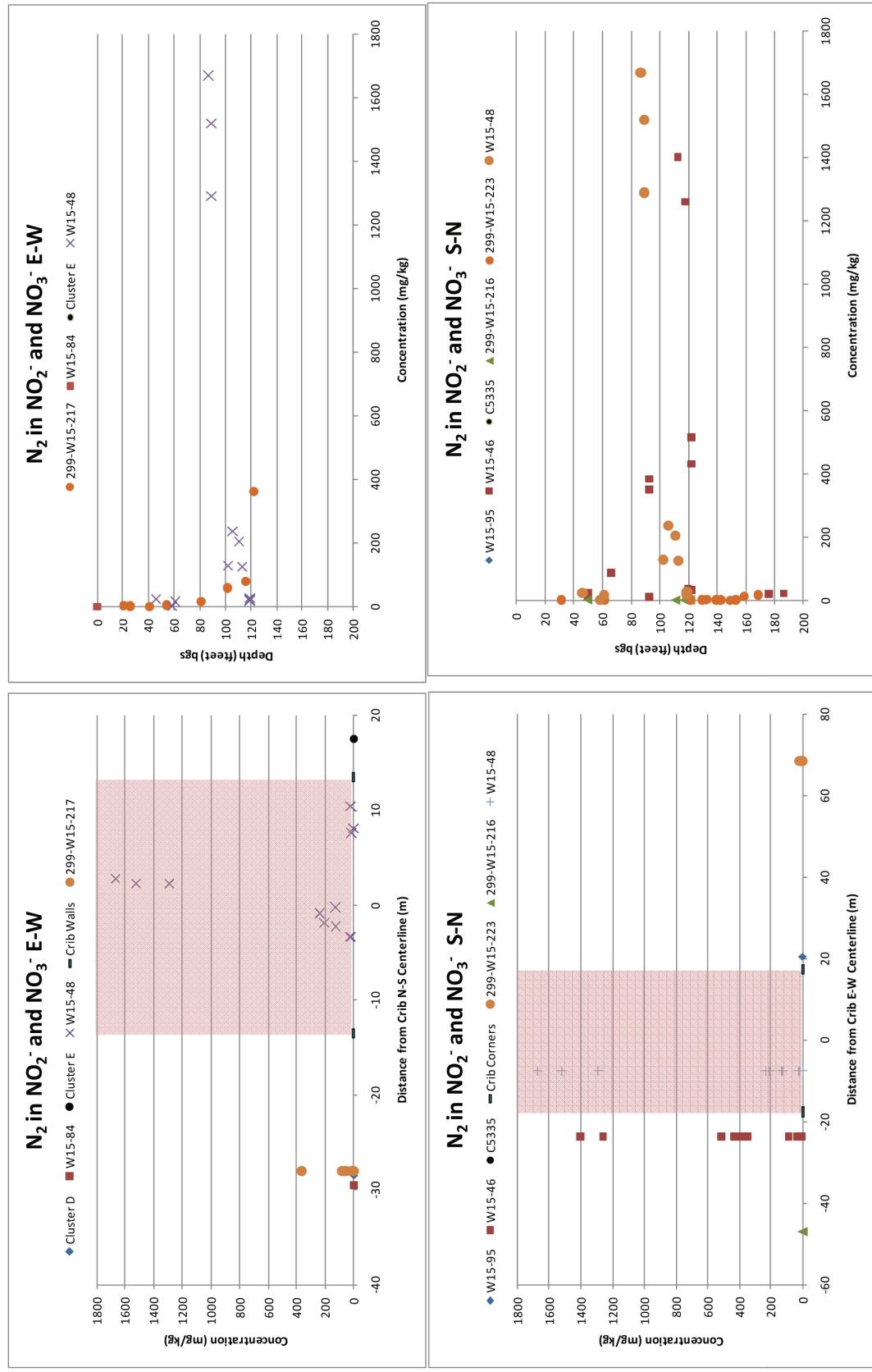
Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-9d. Lateral Patterns of Vadose Zone Soil Concentrations for Tetrachloroethene with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site



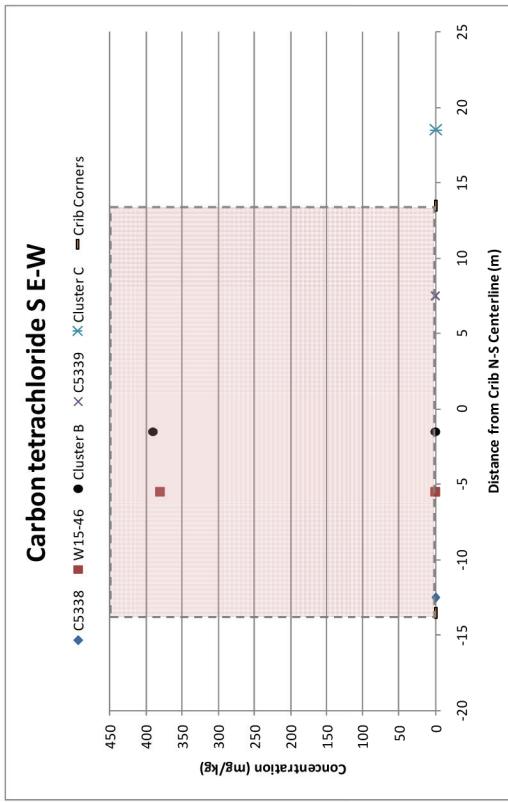
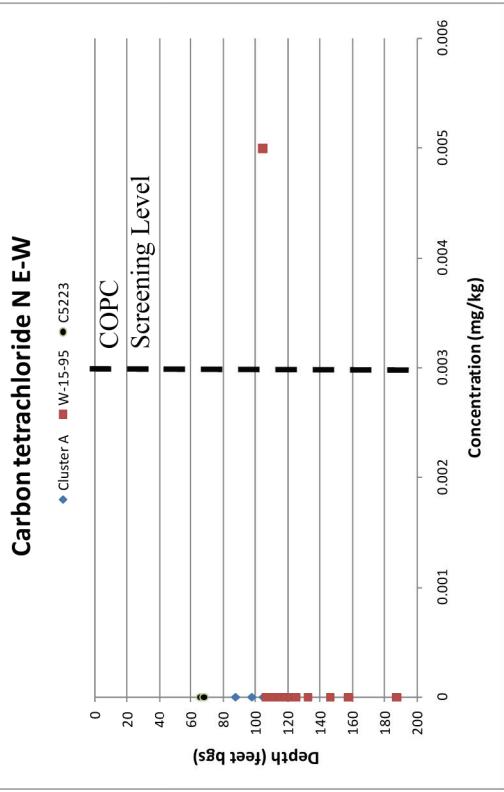
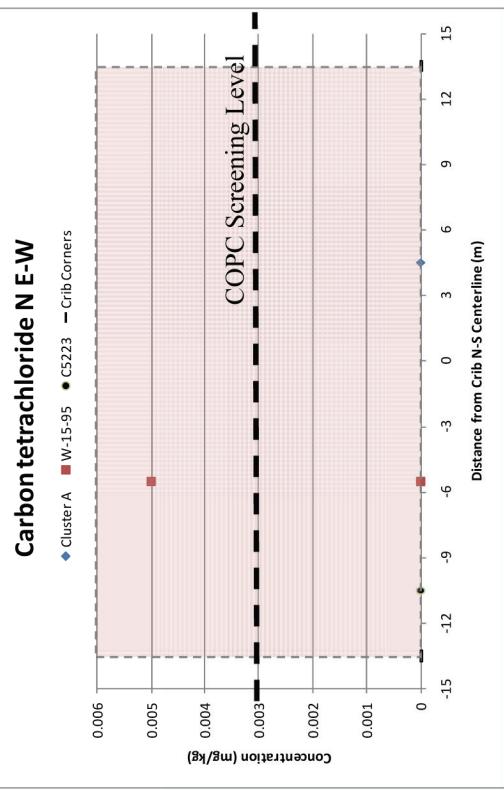
Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-9e. Lateral Patterns of Vadose Zone Soil Concentrations for Hexachloroethane with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site



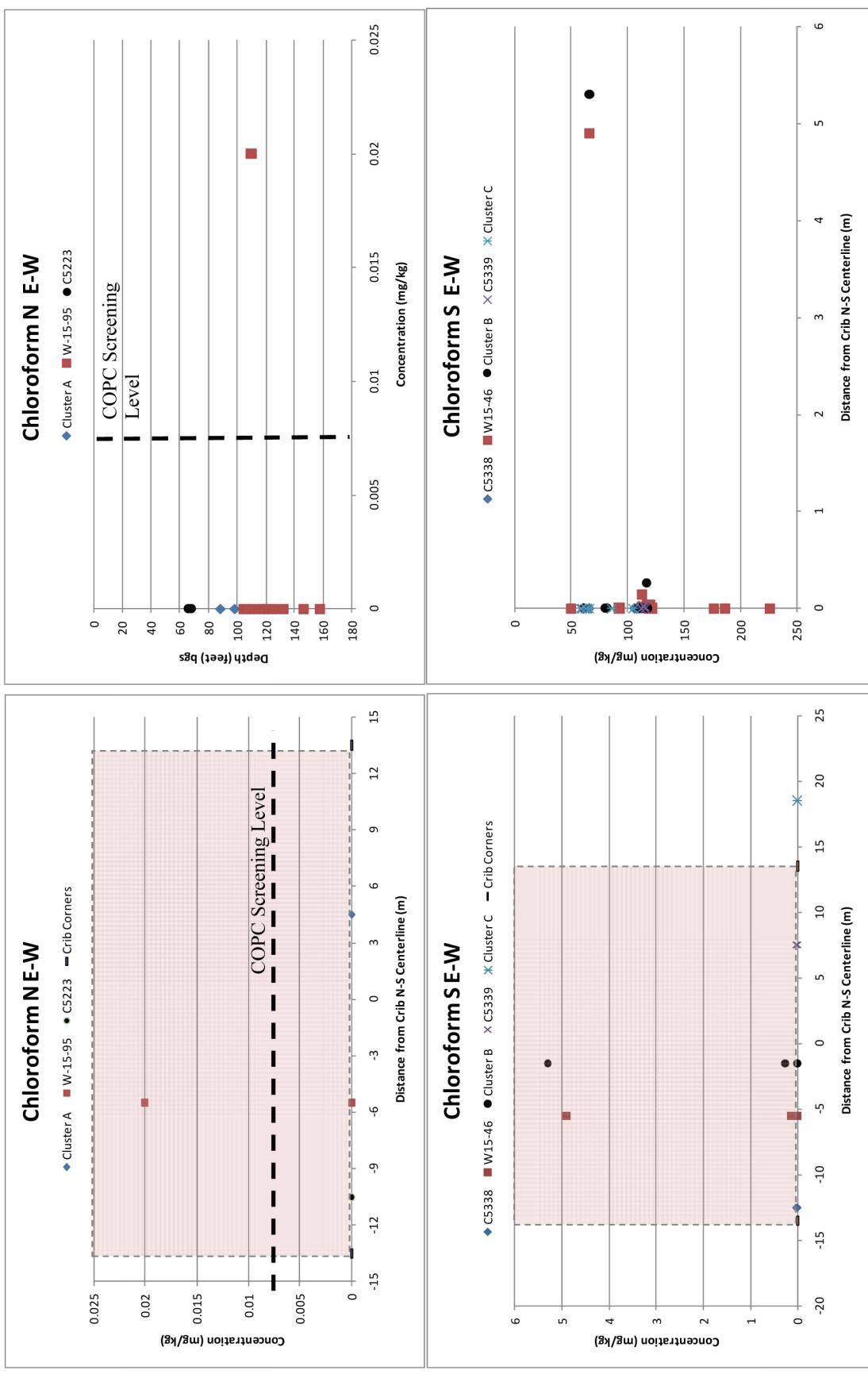
Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-9f. Lateral Patterns of Vadose Zone Soil Concentrations for Nitrogen in Nitrate+Nitrite with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site



Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. The data for the W-E transects adjacent to the north and south boundaries of the Crib are labeled as N E-W and S E-W, respectively.

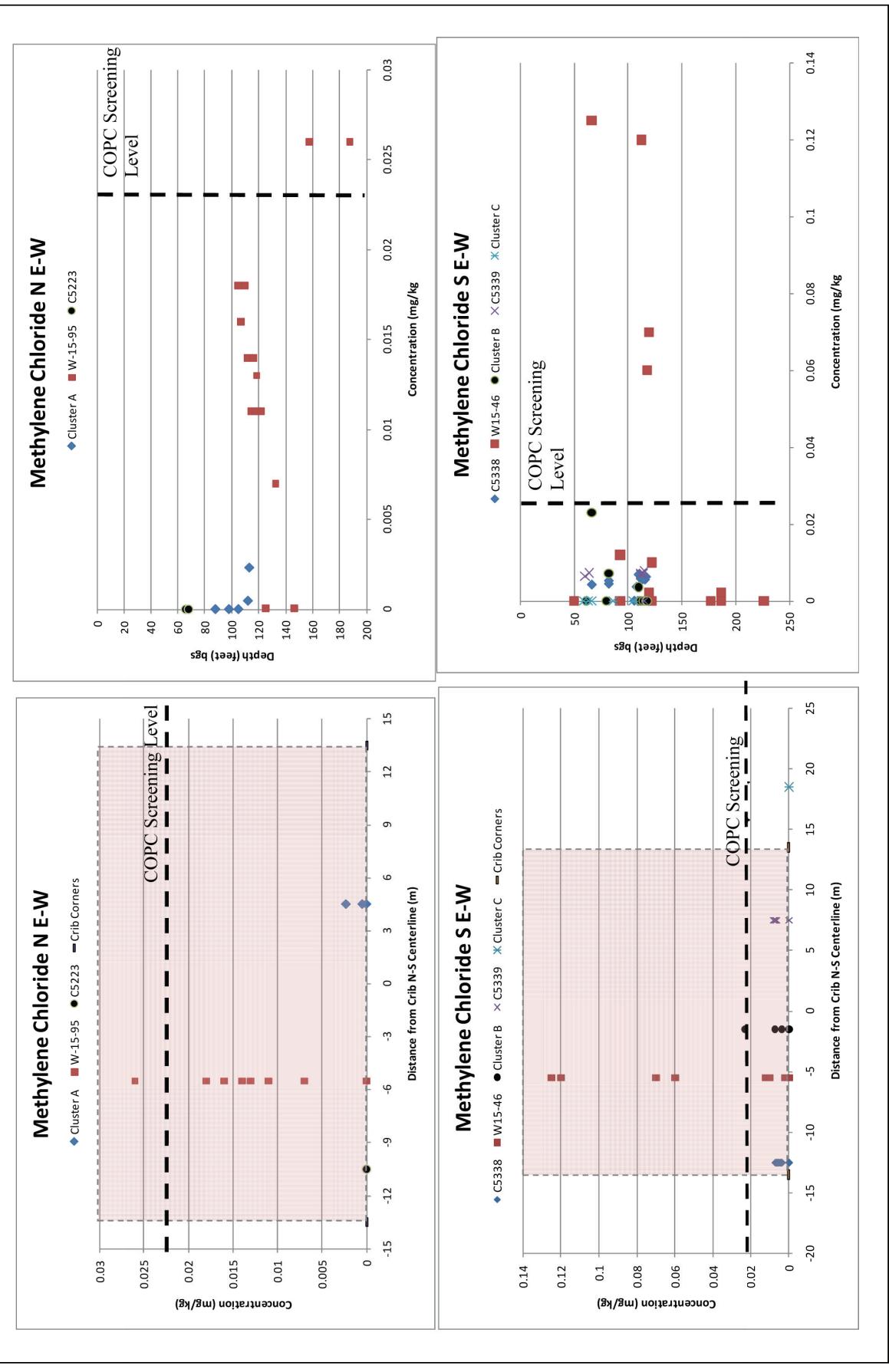
Figure E4-10a. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib



Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. The data for the west-east transects adjacent to the north and south boundaries of the Crib are labeled as N E-W and S E-W, respectively.

Figure E4-10b. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib

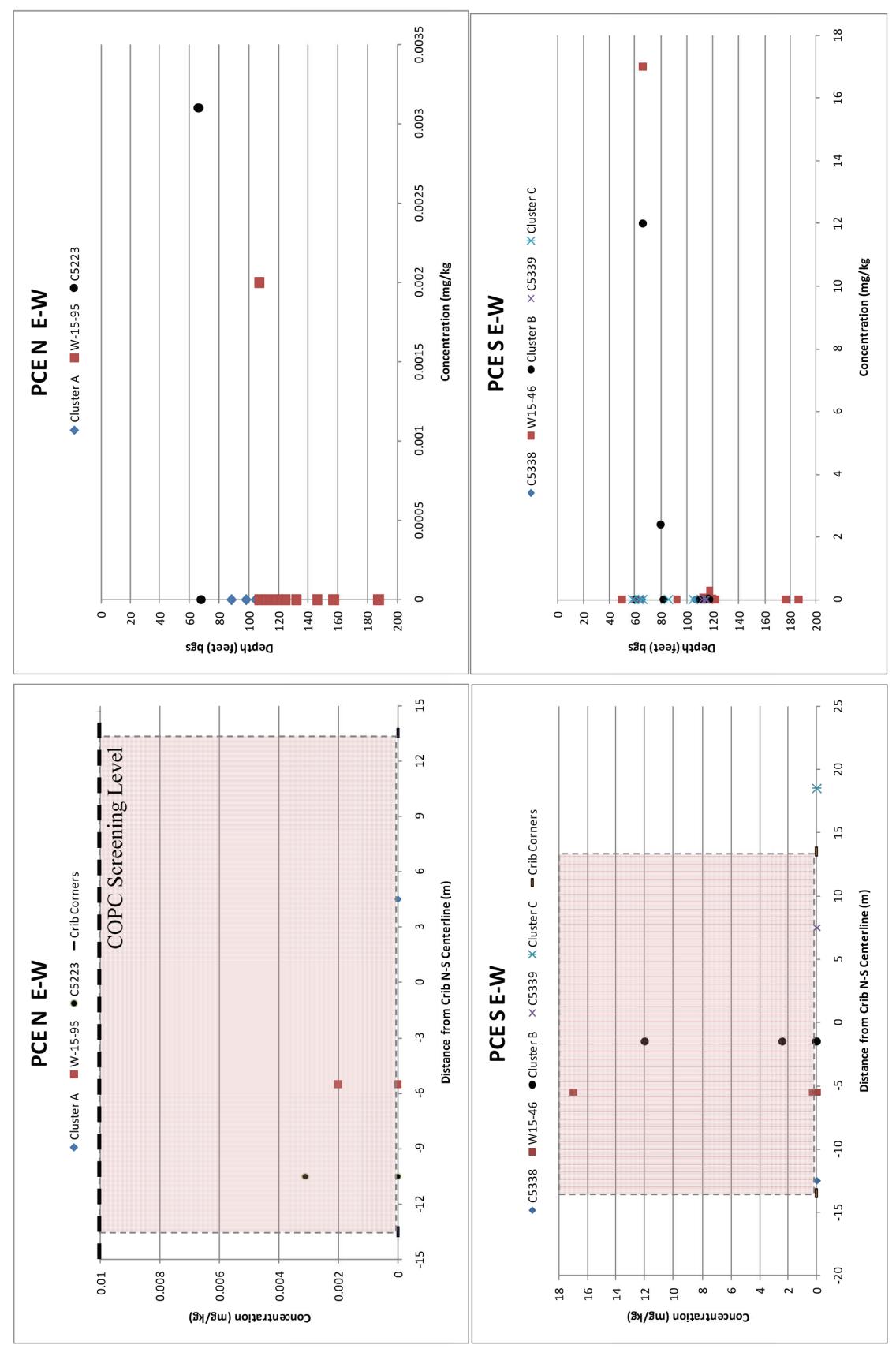
CHPLIBS103-01-139



Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. The data for the W-E transects adjacent to the north and south boundaries of the Crib are labeled as N E-W and S E-W, respectively.

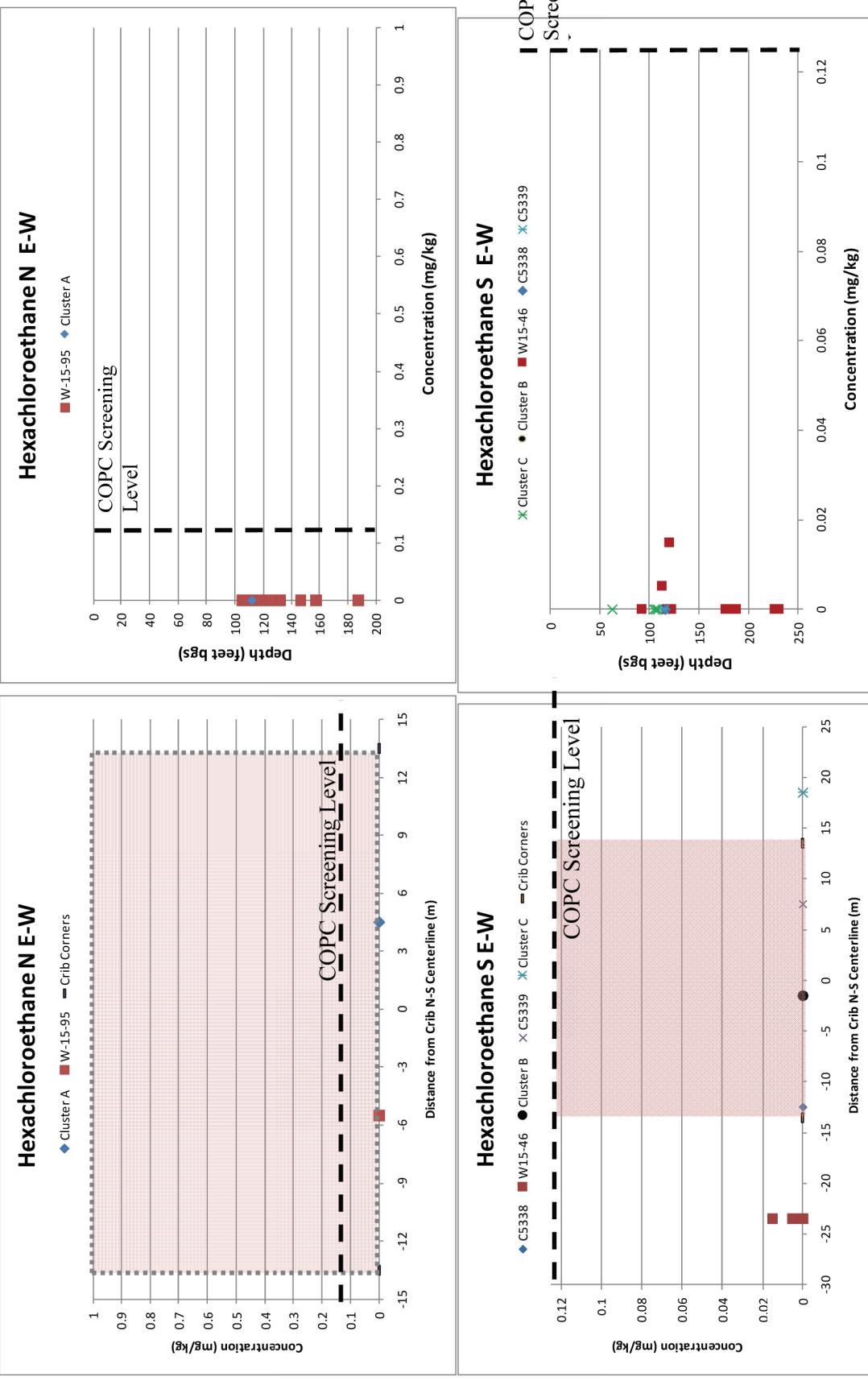
Figure E4-10c. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib

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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. The data for the W-E transects adjacent to the north and south boundaries of the Crib are labeled as N E-W and S E-W, respectively.

Figure E-10d. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib



Note: The location of the Crib footprint in the transects is depicted by the highlighted (pink) areas. The data for the W-E transects adjacent to the north and south boundaries of the Crib are labeled as N E-W and S E-W, respectively.

Figure E-10e. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib

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Distinct patterns of COPC soil concentrations can be seen from evaluation of the data in the 216-Z-9 transects and associated soil concentration depth profiles. These evaluations included the comparison of the patterns of COPC concentrations in the N-to-S and W-to-E transects, and assessment of the lateral and vertical locations of where the elevated levels of contamination in the vadose zone occur. The following is a summary of the patterns of COPC soil concentrations resulting from these evaluations:

1. The highest levels of contamination for all COPCs occur, and appear to be limited to zones beneath the footprint of the waste site in the 299-W-15-48 slant borehole, and/or subsurface soils within about 10 m (33 ft) of the southern edge of the waste site (the 299-W15-46, and Cluster B).
2. Very high levels of contamination do not appear to extend laterally outward beyond the northern, eastern, or western margins of the waste site (footprint), or beyond 10 m (33 ft) of the southern margin.
3. The highest levels of contamination beneath the footprint and the southern edge of the waste site appear to be largely confined vertically to two main depth intervals: a) a contaminated depth interval from about 18 to 24 m (60 to 80 ft) bgs, and b) the Cold Creek sediments (approximately 32 to 38 m [105 to 125 ft] bgs) that are correlated to specific (finer-grained) lithologies.
4. There is a strong correlation in the spatial and concentration patterns of all VOAs evaluated.
5. There are very few data (e.g., ≤ 4) with highly elevated levels of contamination for any of the evaluated COPCs, and for most COPCs, there are also few values above screening levels.

These spatial patterns of COPC soil concentrations in the vadose zone beneath the 216-Z-9 Crib are similar to those observed beneath the 216-Z-1A Crib, but are better defined due to more abundant and spatially diverse data at 216-Z-9. Although meaningful transects could not be constructed for some key COPCs such as Tc-99 and hexavalent chromium, they appear to follow same spatial and concentration patterns observed for other COPCs e.g., (1), (2), and (3), and (5) in the aforementioned section. It would, therefore, appear that the general patterns observed for the COPCs evaluated in the transects and concentration depth profiles apply to all or most organic and non-organic relatively mobile COPCs (e.g., having low K_d values <0.3 mL/g. The patterns observed for nitrogen (nitrate+nitrite) probably best represent the nature of spatial soil concentration patterns for other mobile inorganic analytes such as Tc-99 and hexavalent chromium.

E4.3.4 COPC Concentration Isopleth Maps for the 216-Z-9 Crib

Concentration isopleth “maps,” i.e., equal concentration contours, for selected COPCs were constructed from the 216-Z-9 borehole data in an attempt to evaluate the lateral extent of contamination and the magnitude of the concentration gradients laterally. This evaluation of borehole data in this manner is limited to cases where there is adequate data for the construction of meaningful two-dimensional contours of COPC soil concentration. The construction of such isopleth maps is possible for the 216-Z-9 Crib due to the density and areal coverage of COPC subsurface sampling and analysis for selected COPCs is extensive (i.e., 41 boreholes/borings surrounding the waste site on all sides).

The data used in the construction of the isopleth maps for the 216-Z-9 Crib were primarily limited to select VOAs because these were the COPC data measured in every borehole/boring sample. Isopleth maps were constructed for the soil concentrations of selected VOAs representing the range of the majority of COPCs at the 216-Z-9 Crib that passed screening. Isopleth maps also provide a weight of evidence for evaluating patterns of contaminant behavior spatially and temporally. Nitrogen in nitrate+nitrite was the only non-VOA COPC evaluated because it was the only significant non-organic COPC with sufficient data for the evaluation. The following are the COPCs for which concentration isopleth figures were constructed:

- Carbon tetrachloride (CT)
- Methylene chloride
- Tetrachloroethene (PCE)
- 1-Butanol
- Nitrogen in nitrate+nitrite

This evaluation is also conducive to the assessment of the changes in the spatial patterns of COPC soil concentrations of the VOAs over time based on data from three periods: 1992 to 1992, 2001 to 2004, and 2006. The soil concentrations of the VOAs are observed to have changed over time due to the operation of the SVE system since 1992 to 1993.⁸

Figure E4-11 shows the trend of average CT soil concentrations beneath the 216-Z-9 Crib over a period of 13 years since 1993. The isopleth maps shown in Figure E4-12 were constructed by calculating the average COPC concentration for the COPC data within the depth interval 15 to 37 m (50 to 120 ft) bgs, for the period of interest. The isopleths for nitrogen in nitrate+nitrite were based the data for this depth interval for all periods, because the soil concentrations for this COPC are not expected to vary over time due to volatilization or operation of the SVE system. The depth interval was selected to represent the vertical portions of the vadose zone over which most of the contamination is observed to occur, and to also allow larger amounts of data to be used in estimating average COPC concentrations. Average concentrations were used in the construction of the isopleth maps as the most representative metric of contaminant source term mass. All isopleths were constructed by hand, using the data shown in the figures, judgment in the interpolation of concentration contours, and the spatial patterns of soil concentration determined from other COPCs.

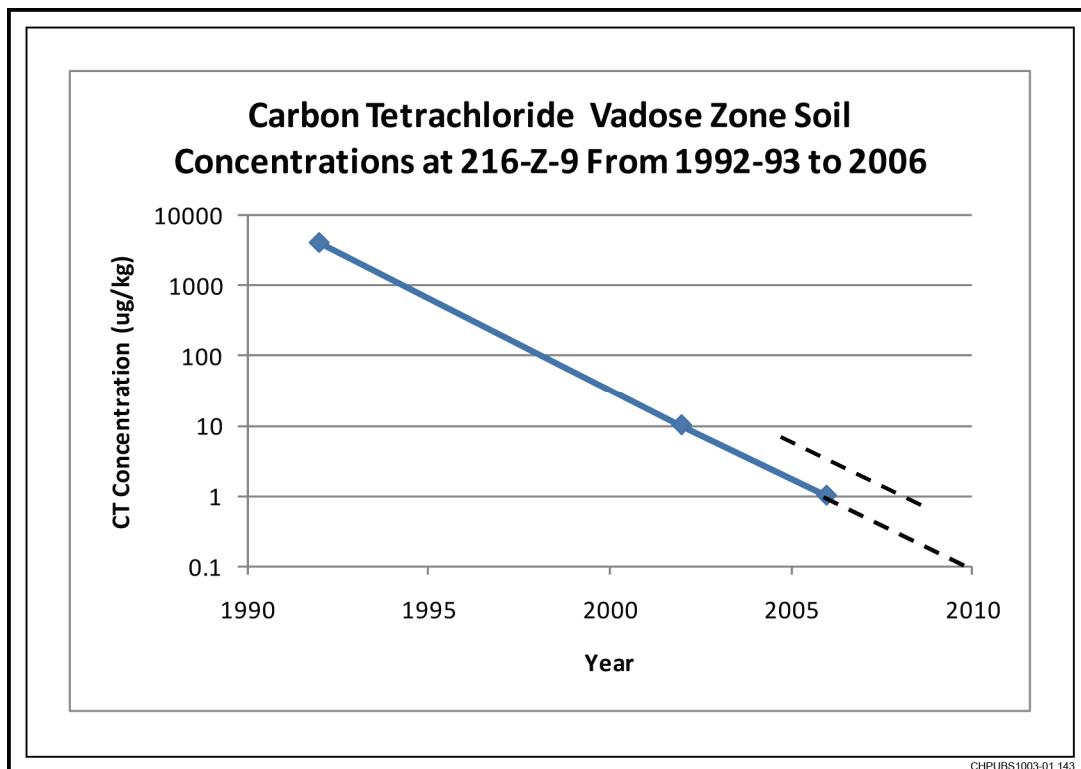
Sufficient data were available to evaluate the spatial patterns of soil concentrations over time for CT (Figure E4-12) and for methylene chloride. Figure E4-12 illustrates the spatial trends in soil CT concentrations, showing concentration isopleths for the periods 1992 to 1993, 2001 to 2004, and 2006. The temporal patterns for methylene chloride (not shown) were similar. The temporal trends in the size and levels of VOA soil concentrations were also evaluated by constructing isopleths (mg/kg) for the sum of all VOA analytes for the three periods as an indicator for the general trends in VOAs over time.

The following are the main conclusions drawn from the evaluation of the isopleth maps and figures:

- The levels of contamination and the lateral extent of VOA soil contamination in the vicinity of the 216-Z-9 Crib have decreased significantly since 1992 to 1993.
- The present spatial pattern of soil contamination for the VOAs is generally symmetrical with respect to the E-W dimensions of the footprint of the 216-Z-9 Crib, but asymmetrical N-S, with the highest levels of contaminated centered at the south edge of the waste site.
- The maximum dimensions of the subsurface contaminant plume greater than the soil screening levels are similar to the footprint dimensions of the waste site.
- The concentration gradients for the VOAs at the southern edge of the 216-Z-9 Crib appear to have become steeper over time.

⁸ The soil concentrations for the VOAs represent only adsorbed +/- interstitial components of contamination, which may dissolved aqueous components, but not vapor components. It is also noted that the concentrations of soil, aqueous, and vapor at equilibrium are related by the physiochemical partitioning relationships between the solid, liquid (free product), aqueous, and vapor phases described by aqueous solubility, vapor pressure, solid-liquid partitioning (e.g., soil-water K_d partition).

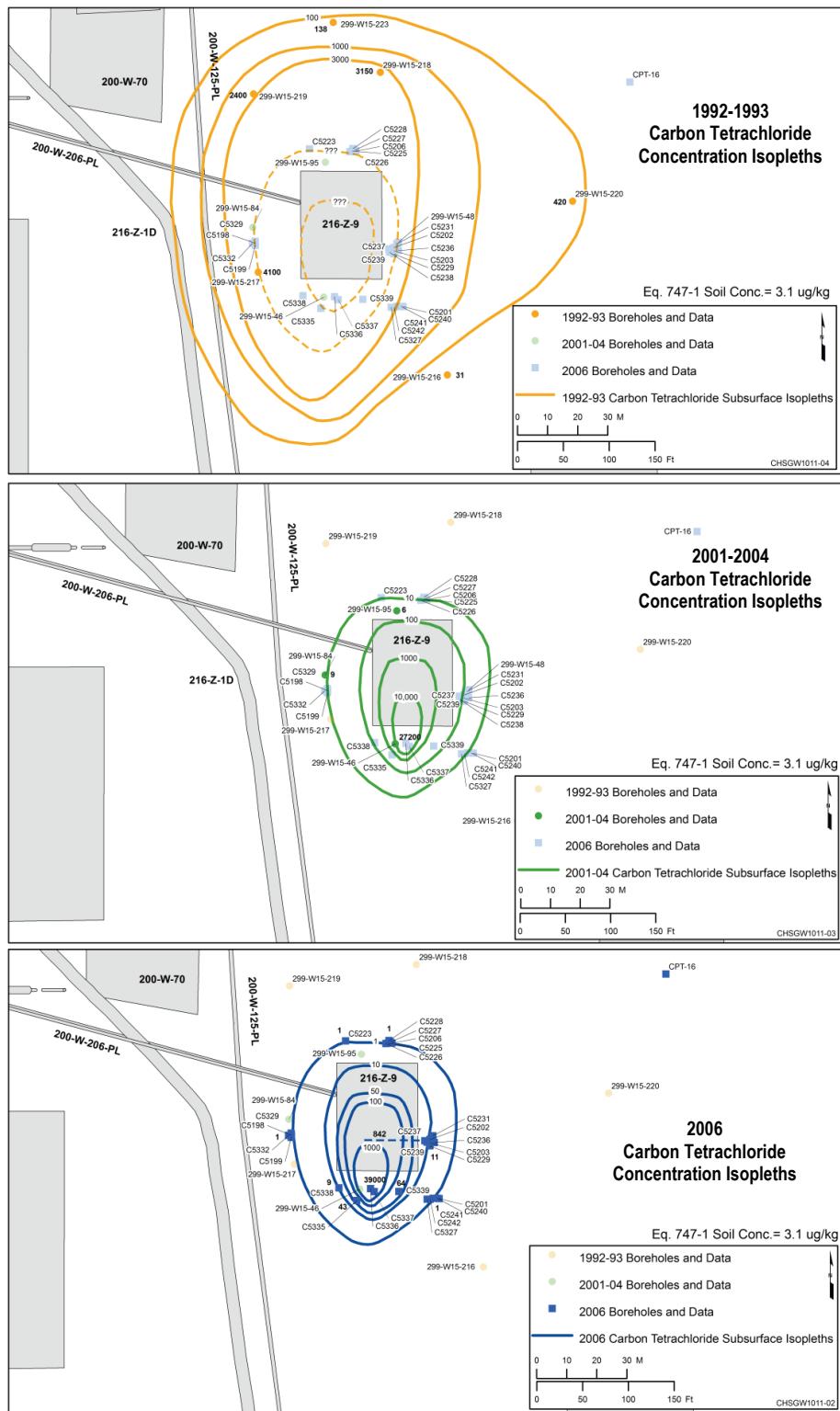
- The spatial and temporal trends in the VOA soil concentrations and the geometry of the contaminant plumes in 2006 are strongly correlated.
- The subsurface plume for nitrogen appears to be laterally more extensive than that for the VOAs in 2006, symmetrically elongated in an N-direction, with the highest concentrations centered at the south edge of the waste site.
- The lateral extent of the nitrogen plume above background levels may be as much as two to three times the footprint dimensions of the waste site.



Note: Concentrations at reference locations around the crib (see Figures E4-12) appear to decrease logarithmically over time (note logarithmic scale for the concentration axis).

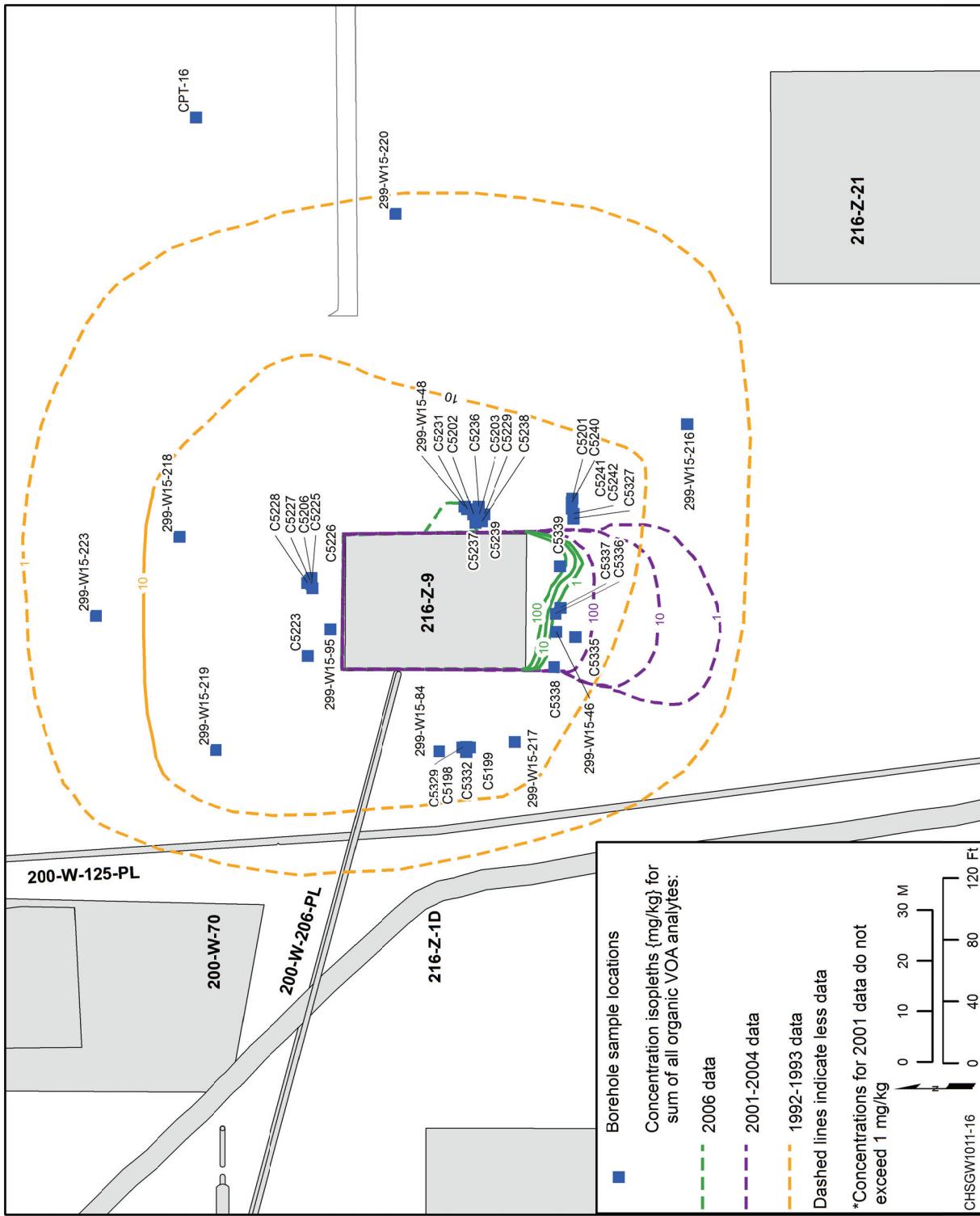
Figure E4-11. Trend of Average CT Soil Concentrations near the 216-Z-9 Crib from 1992 to 1993 to 2006, for the Depth Interval from 15 to 37 m (50 to 120 ft) bgs

Detailed evaluation of the temporal trends in the decrease of CT soil concentrations over time indicate that the concentrations have decreased logarithmically from 1992 to 1993 to 2006, by over three orders of magnitude (e.g., decrease of up to 4,000 times), ostensibly due to the operation of the SVE system (Figure E4-11). The pattern and magnitude of reduction in concentration over time for most, if not all, VOAs, appear to follow the same general pattern as CT (see Figure E4-12). The isopleths for the sum of the soil concentrations for all VOA analytes in Figure E4-13 show the same general pattern of decrease in the lateral dimensions of the contaminant plume and concentrations over time, and steeper concentration gradients at the southern edge of the waste site. Although isopleth plots for the sum of concentrations for all VOA analytes in Figure E4-13 have been shown to be useful in CERCLA or RCRA compliance work in the U.S. Department of Defense (DOD) complex these relationships alone are not necessarily compelling. This is because they can incorporate sampling bias, e.g., due to the frequency of measurement locations and depths, which can also differ by COPC, and sampling date. However, these



Note: Average COPC borehole concentrations and isopleths ($\mu\text{g}/\text{kg}$) are for the depth interval 15 to 37 m (50 to 120 ft) bgs.

Figure E4-12. Carbon Tetrachloride Subsurface Isopleths—1992-2006 with Respect to the 216-Z-9 Footprint



Note: Concentration isopleths (mg/kg) are for the sum of all VOAs.

Figure E-13. 216-Z-9 Temporal Trends of the Total VOA Soil Contamination Footprint in the Context of the 216-Z-9 Footprint

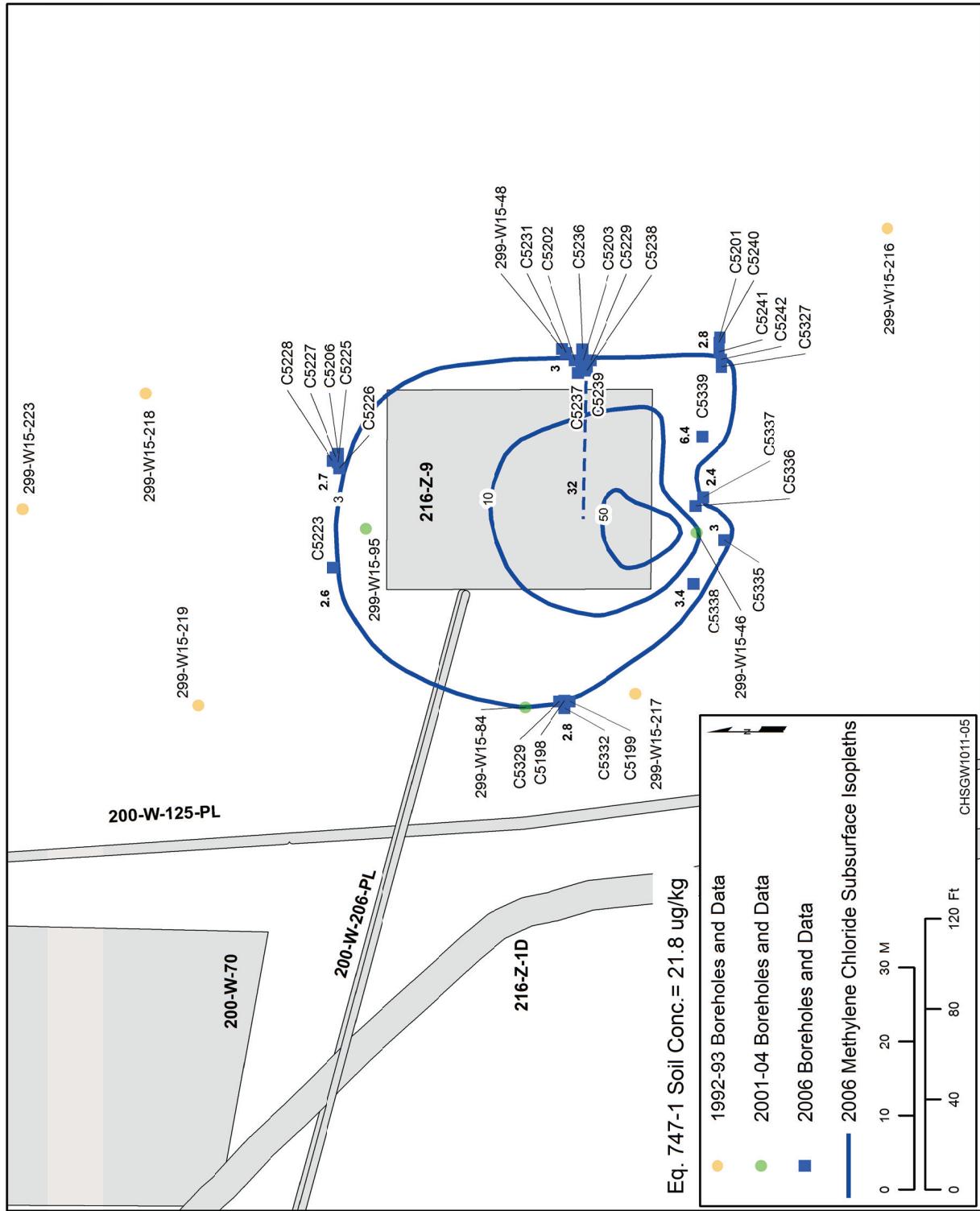
1 relationships coupled with the patterns of VOA behavior seen in isopleth Figures E-14 to E-16, which are
2 analyte-, depth-, and time-specific, provide a compelling weight of evidence for these COPC patterns of
3 behavior.

4 It is also inferred from this evaluation that the present (Year 2010) VOA concentrations in soil should be
5 even lower than those observed in 2006, possibly by as much as an order of magnitude, based on an
6 additional four years of SVE operation, and extrapolation of the concentration trend shown in
7 Figure E4-11; however, extrapolated trends are dependent on the point at which the efficiency of the SVE
8 reaches the point of diminishing return; i.e., flattening trend of concentration reduction with time. It can
9 also inferred that the lateral extent and spatial patterns of subsurface soil concentrations (e.g., lateral
10 gradients) for nitrate in the beneath the 216-Z-9 waste site and concentration patterns applicable to other
11 mobile inorganic COPC, e.g., Tc-99. Analogous behavior of e.g., Tc-99 to nitrate is expected from the
12 contaminant behavior conceptual model, because both COPCs are mobile COPCs with assumed K_d values
13 of 0 mL/g, and which are expected to have spatial patterns of contamination that largely followed the
14 water plume associated with the liquid discharges at the waste site.

15 It is also reasonable to assume that the patterns of COPC behavior, and insight gained on the nature and
16 extent of contamination at the 216-Z-9 Crib where there is a nearly unprecedented wealth of data,
17 logically have implications and applications for other Hanford waste sites where fewer data are available.
18 The extrapolation of the deductions and conclusions pertaining to the nature and contamination extent at
19 the 216-Z-9 waste site, for example, are most applicable to waste sites with similar or comparable waste
20 streams and/or waste discharge/disposal histories. Thus, the conclusions should be directly applicable to
21 the other 200-PW-1/6 waste sites (i.e., 216-Z-1A and 216-Z-18). These findings may also serve as a case
22 study and basis for establishing or bounding the lateral extent of selected COPCs in the vadose zone.

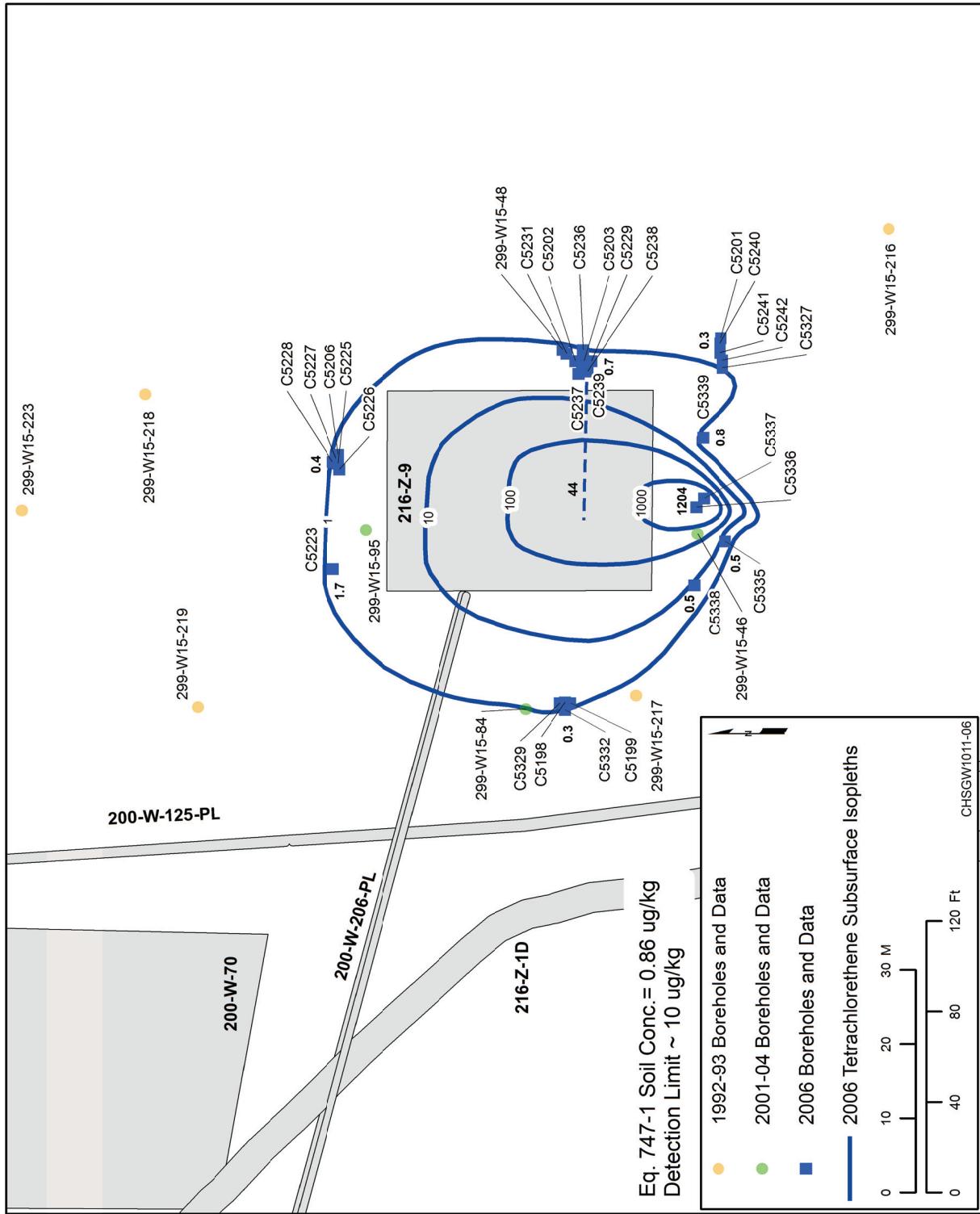
23 The relationships shown for the COPCs in these isopleth maps are only as valid as the data from which
24 they were constructed, and the assumptions associated with their construction. For example, although the
25 isopleths are the average COPC concentrations for the data collected over the depth interval from 15 to
26 37 m (50 to 120 ft) bgs, this does not necessarily mean that these average concentrations accurately
27 represent the weighted average of concentrations throughout the plume. This is because the average
28 concentration determined in this manner incorporates the collective biases associated with, e.g., sample
29 location bias, in terms of both lateral coverage, and depth, and frequency of analysis. The lateral extent of
30 contamination portrayed by the isopleths, for example, incorporate a bias due to a greater frequency of
31 data in most contaminated regions of the vadose zone, which are typically preferentially sampled. At the
32 216-Z-9 Crib, there appears to be some preferential sampling of the depth intervals just above and within
33 the Cold Creek unit, where the concentrations of COPCs are typically highest for most COPCs, and also
34 where the extent of lateral spreading is known or expected to be the greatest. It is, therefore, important to
35 understand the limitations of such constructs, in terms of what they do, and do not to represent. The
36 lateral extent of the 2-D isopleths shown in Figures E4-12 and E4-14 to E4-17, are effectively the average
37 lateral extent of contamination over the depth interval from 15 to 37 m (50 to 120 ft) bgs. Thus, they do
38 not provide information to distinguish whether the lateral extent of contamination varies with depth in the
39 vadose zone. Therefore, the lateral extent of the contamination plume for many, if not all, COPCs may be
40 smaller in the shallower parts of the vadose zone than in the Cold Creek unit, or as depicted by the 2-D
41 isopleths. This depends on the extent to which the lateral extent of contamination in the shallower parts of
42 the vadose zone differs from that deeper in vadose zone in the vicinity of the Cold Creek unit, as well as
43 on the extent to which the data represent preferential sampling over one or more depth intervals. This is
44 an important issue for understanding the uncertainties and biases associated with the input parameters for
45 fate and transport modeling.

46



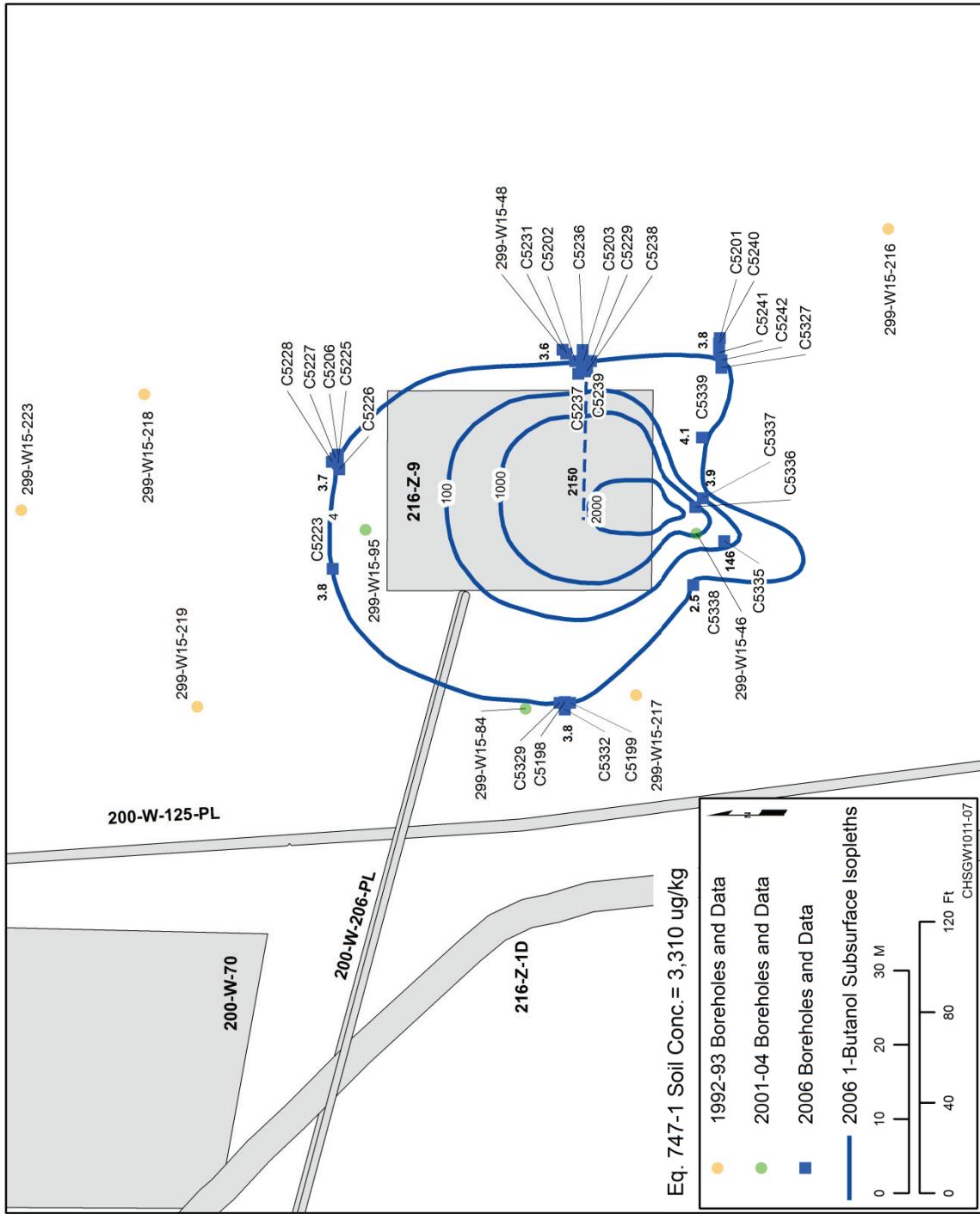
Notes: 2006 data. Average COPC borehole concentrations and isopleths ($\mu\text{g}/\text{kg}$) are for the depth interval 15 to 37 m (50 to 120 ft) bgs.

Figure E4-14. 216-Z-9 Methylene Chloride Subsurface Isopleths with Respect to the 216-Z-9 Footprint



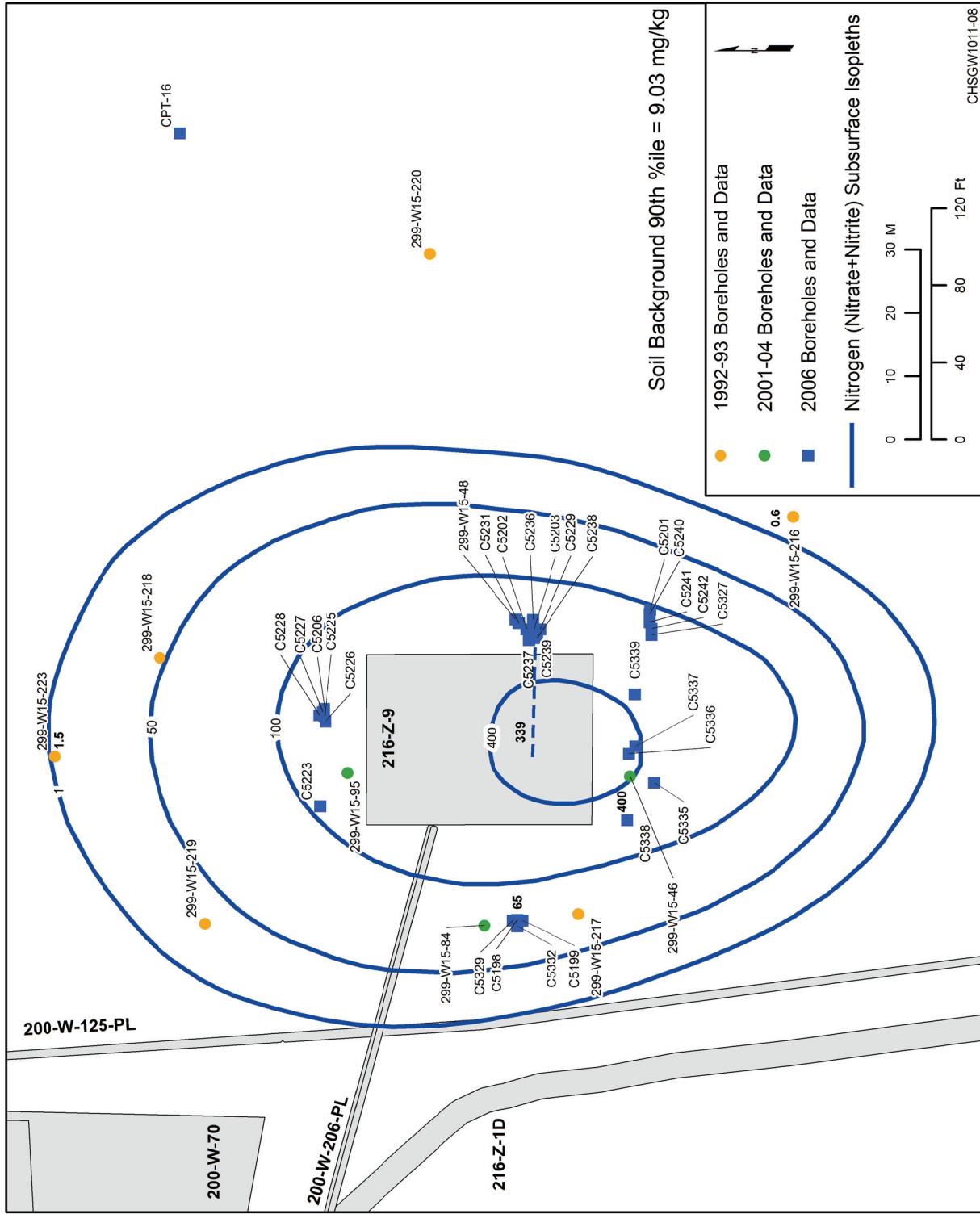
Note: 2006 data. Average COPC borehole concentrations and isopleths (ug/kg) are for the depth interval 15 to 37 m (50 to 120 ft) bgs.

Figure E4-15. Tetrachloroethene Subsurface Isopleths with Respect to the 216-Z-9 Footprint



Note: 2006 data. Average COPC borehole concentrations and isopleths ($\mu\text{g}/\text{kg}$) are for the depth interval 15 to 37 m (50 to 120 ft) bgs.

Figure E4-16. 1-Butanol Subsurface Isopleths with Respect to the 216-Z-9 Footprint



Note: 2006 Data. Average COPC borehole concentrations and isopleths ($\mu\text{g}/\text{kg}$) are for the depth interval 15 to 37 m (50 to 120 ft) bgs.

Figure E4-17. Nitrogen (Nitrate+Nitrite) Subsurface Isopleths with Respect to the 216-Z-9 Footprint

1 **E4.3.5 Three-Dimensional COPC Plumes for 216-Z-9**

2 The COPC soil data from the boreholes and borings in the area surrounding the 216-Z-9 Crib were also
3 used to construct 3-D depictions of the contaminant plume for CT and for nitrogen (in nitrate+nitrite).
4 These two contaminants were selected as the COPCs best representing the spatial patterns of the VOA
5 COPCs (CT), and the mobile non-organic COPCs (nitrogen). The 3-D depictions of the subsurface
6 contamination provide a method for evaluating the spatial distribution of the soil contaminants that
7 integrates the entire array of borehole data, and minimizes the effects of sampling, and measurement
8 frequency biases in the construction of subsurface soil plume geometry. Figures E4-18 through E4-21
9 show a north-looking W-E cross-sectional view and a plan view of the 3-D plumes for both contaminants.
10 These show the relationship of the crib dimensions and location to that of the contaminant plumes.

11 The evaluation of the CT and nitrogen spatial distribution and soil concentration gradients based on the
12 3-D depiction of the contaminant plumes corroborate the conclusions and inferences from the evaluation
13 of, and comparison to, the soil concentration isopleths for the 216-Z-9 Crib and the transects across the
14 216-Z-1A and 216-Z-9 waste sites. However, the 3-D plumes provide perspective, detail, and insight
15 regarding the extent and geometry of the plumes that could not otherwise be recognized. These 3-D
16 depictions also provide the most representative perspective on the spatial extent of contamination and
17 contamination gradients both laterally and vertically; thus, this manner of evaluation of the subsurface
18 contaminant plumes truly provide a new dimension to the manner in which subsurface contamination can
19 be evaluated, as well as additional perspective and refinements to the evaluation of the nature and extent
20 of subsurface contamination.

21 As inferred from comparing the lateral trends of COPC soil contaminations across the 216-Z-1A and
22 216-Z-9 Cribs, and COPC isopleths beneath the 216-Z-9 Crib, the information and insight gained from
23 evaluating the contaminant plumes for these two COPCs can serve as reference cases for understanding
24 and defining the spatial behavior of other contaminant at other waste sites. Perhaps one of the most
25 valuable applications associated with the use of the 3-D plume information concerns the calculation of
26 representative soil concentrations. The ability to evaluate the soil concentration throughout various parts
27 of the contaminant plume provides insight into the manner in which COPC soil concentrations are
28 determined, that serve as the source terms for vadose zone fate and transport modeling. Section E4.4.4
29 describes and discusses this insight pertaining to the calculation of representative COPC concentrations
30 for specified soil volumes.

31 **E4.3.6 Other Factors Pertaining to the Contaminant Source Term Conceptual Model**

32 Other factors that are important for understanding the spatial distribution and concentrations of the VOAs
33 in the 200-PW-1 vadose zone are the physical and chemical properties that control their geochemical
34 behavior and the tendency for their concentrations and spatial extent to be affected (reduced) by the SVE
35 system. This section discusses the rationale for similarities and/or differences in the contaminant behavior
36 conceptual of the VOA COPCs beneath the 200-PW-1 (Z-Area) waste sites as a basis for assumptions
37 concerning analogous behavior among VOA COPCs, including the relative dimensions of contaminant
38 soil volumes.

39

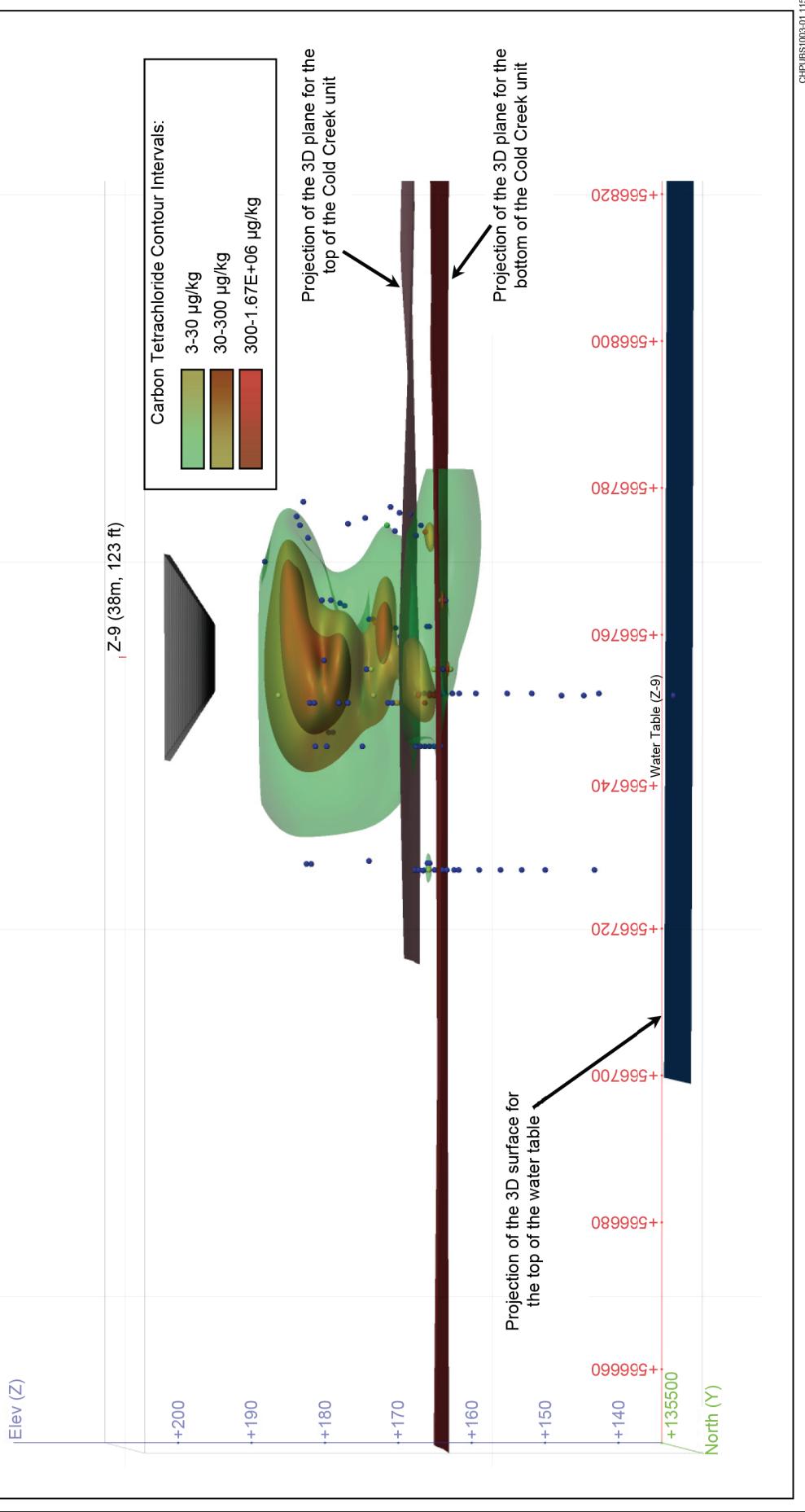
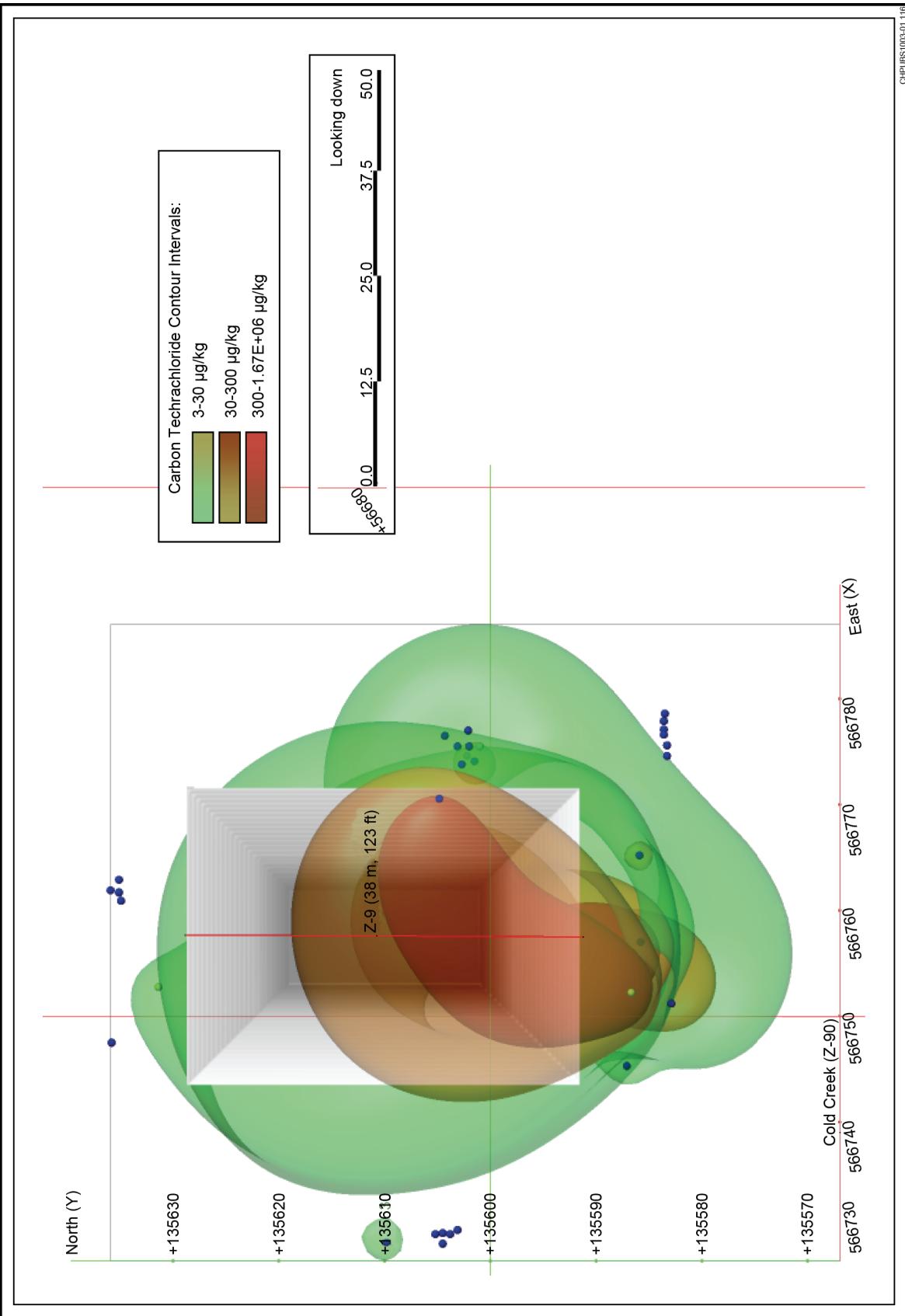


Figure E4-18. North-Looking, W-E Cross-Section Showing a 3-D Portrayal of the CT Contaminant Plume in the Vadose Zone Beneath the 216-Z-9 Crib and the Relationship of the Crib Cross-Section to the Contaminant Plume



Note: The outermost plume boundary (green) denotes the 0.00351 mg/kg screening level contour, the outermost part of two brown-colored zones denote the 0.030 mg/kg, and the 0.300 mg/kg contours.

Figure E4-19. Plan View of a 3-D Portrayal of the CT Contaminant Plume in the Vadose Zone Beneath the 216-Z-9 Crib Showing the Relationship of the Crib Footprint to the Plume

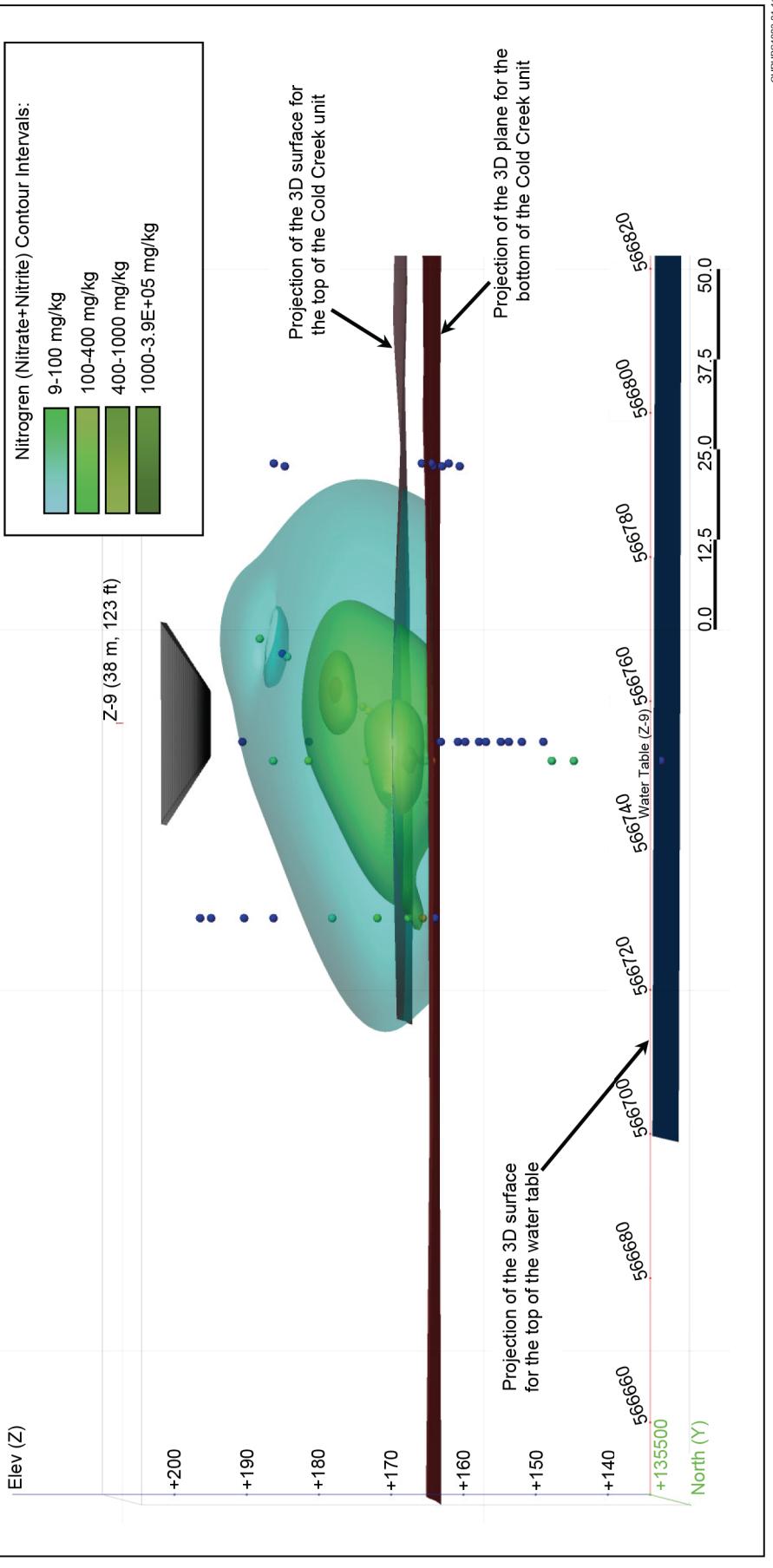
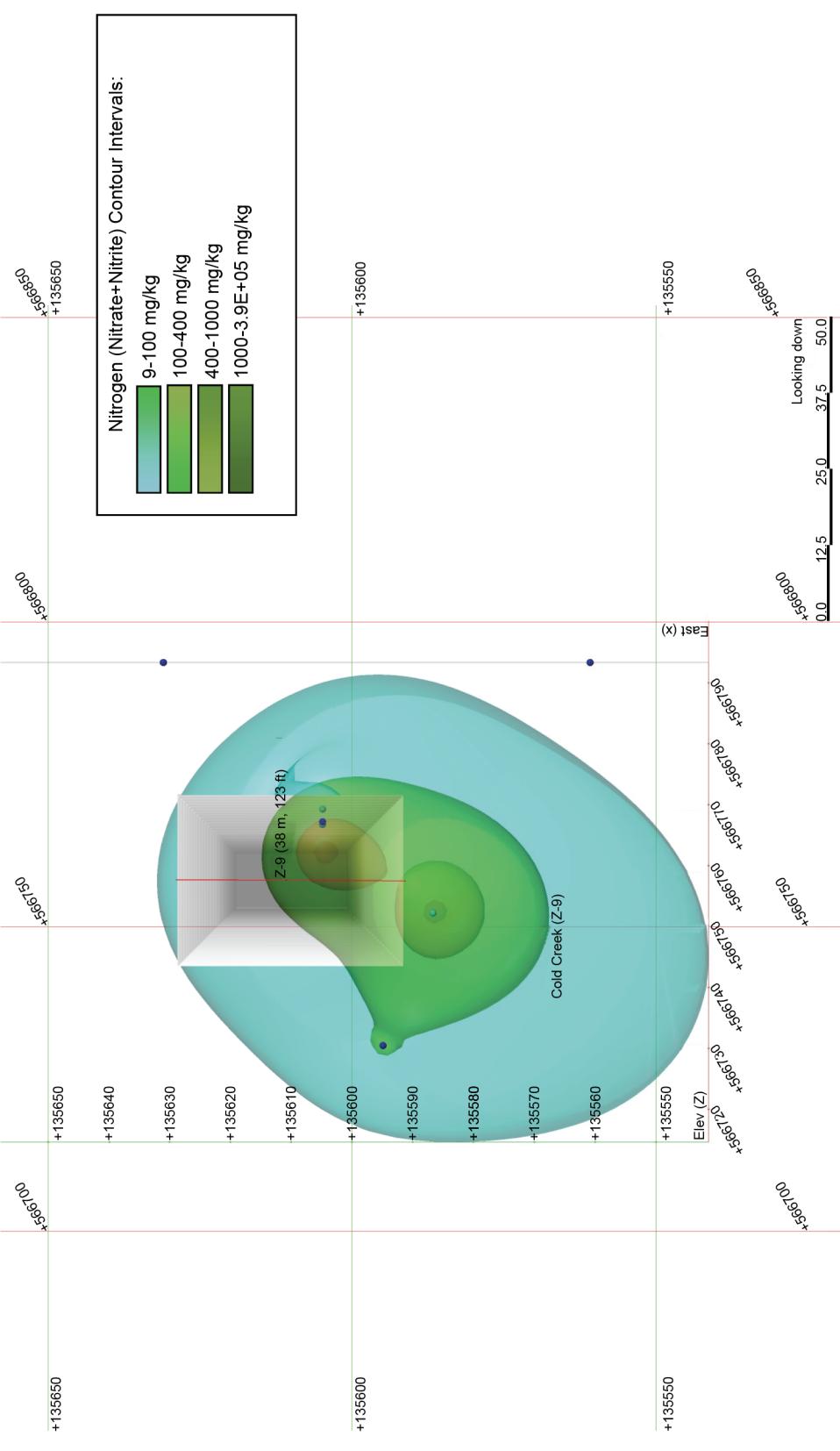


Figure E4-20. North-Looking, W-E Cross-Section Showing a 3-D Portrayal of the Nitrogen (Nitrate+Nitrite) Contaminant Plume in the Vadose Zone Beneath the 216-Z-9 Crib and the Relationship of the Crib Cross-Section to the Contaminant Plume



Note: The outermost plume boundary (blue) denotes the 9 mg/kg background screening level contour, the outermost part of three green-colored zones denote the 100 mg/kg, the 400 mg/kg contours, and the 1,000 mg/kg contour for the small innermost core zone of the plume.

Figure E4-21. Plan View of a 3-D Portrayal of the CT Contaminant Plume in the Vadose Zone Beneath the 216-Z-9 Crib Showing the Relationship of the Crib Footprint to the Plume

1 Some of the main physical and chemical properties that control the geochemical behavior of the VOA
 2 COPCs include the specific gravity, vapor pressure, water solubility and phase partitioning (e.g., water
 3 solubility, Henry's Law behavior) as identified in Table E4-2. These properties are important
 4 characteristics of the VOAs because they define the manner in which the VOAs are effectively partitioned
 5 between the free product (liquid) phase, vapor phase, aqueous phase, and sorbed phases as indicated in
 6 Table E4-2. The concentrations of soil, aqueous, and vapor at equilibrium are related by the
 7 physiochemical partitioning relationships between the solid, liquid (free product), aqueous, and vapor
 8 phases described by aqueous solubility, vapor pressure, solid-liquid partitioning (e.g., soil-water K_d
 9 partition). The soil concentrations for the VOAs represent only adsorbed +/- interstitial components of
 10 contamination that may dissolved aqueous components, but not soil vapor components.

Table E4-2. Comparison of Key Physical and Chemical Phase Partitioning Properties of Some Groundwater Protection VOA COPCs in the Vadose Zone at the 200-PW-1 Waste Sites

COPC	Specific Gravity (g/cm ³)	Water Solubility (K _{sp}) g/100 mL	Vapor Pressure (mm Hg at 25 °C)	Henry's Law Constant (atm-m ³ /mole)	Soil-Water Partition Coefficient (adsorption K_d ; mL/g)
Phase partitioning	--	Water-Liquid (Free Product)	Gas-Liquid (Free Product)	Gas-Water	Soil (Sorbed)-Water
Carbon tetrachloride	1.59	0.08	91.3	2.9E-02	0.15
Chloroform	1.48	0.8	160	3.7E-03	0.05
Dichloromethane (methylene chloride)	1.33	1.3	400	2.57E-03	0.01
Tetrachloroethene (PCE)	1.62	0.015	18.5	1.8E-02	0.25
Trichloroethene (TCE)	1.46	0.13	58	1.1E-02	0.1
1,1-Dichloroethane	1.2	0.6	230	1.8E-02	0.05
1-Butanol	0.81	7.7	7.0	8.81E-06	0.01

11 Many of the COPCs passing the screening steps are halogenated hydrocarbons that have similar physical
 12 and chemical properties, similar geochemical behavior and are, therefore, expected to have similarities in
 13 the nature and extent of the subsurface contaminant plumes. As seen in Table 4-2, all but one of the
 14 COPCs (1-butanol) are chlorinated hydrocarbons that are denser than water (DNAPL), relatively volatile,
 15 with a range of water solubilities, and not strongly retarded by sorption during aqueous transport. The
 16 nature and distribution of many of these COPCs are also expected to be similar because they are related in
 17 terms of their chemical structures. Four of the COPCs in Table E4-2 are related by the degradation
 18 (breakdown products) of CT (chloroform, dichloroethane, methylene chloride) as shown in
 19 Figure E4-22(a). Two others, tetrachloroethene and trichloroethene, are similarly related to one another as
 20 illustrated in Figure E4-22(b).

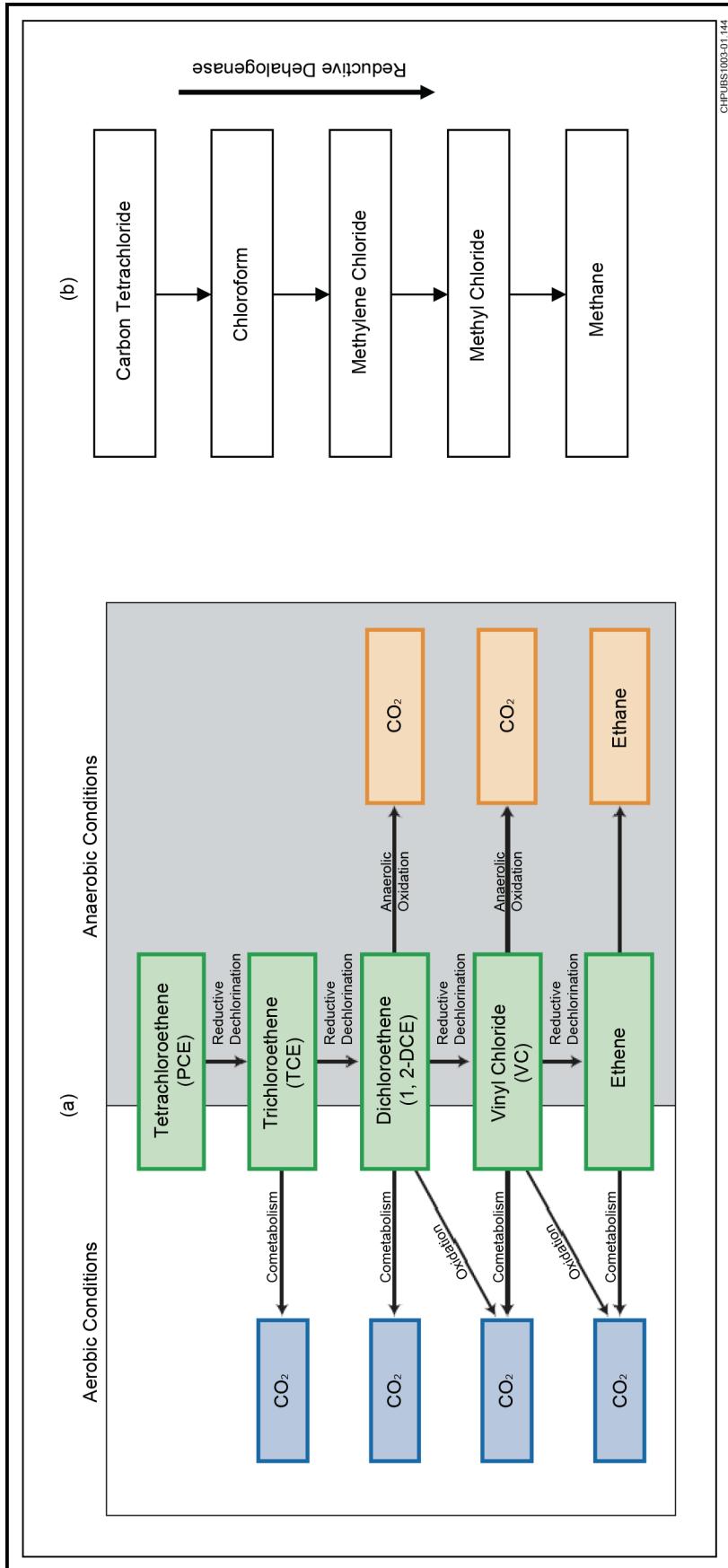


Figure E4-22. Degradation Pathways for (a) PCE/TCE, and (b) CT

1 Note: Adopted from Hazardous Substance Research Centers, 2005. www.hsrc.org/prague/major

2

3

4

1 Although 1-butanol is not a halogenated hydrocarbon, and has some properties that differ significantly
 2 from those of the halogenated hydrocarbons (e.g., specific gravity, water solubility, Henry's Law
 3 constant), it has a large enough vapor pressure to also be subject to source term removal by the SVE
 4 system. It is also notable that two of the VOAs listed in Table 4-2 (methylene chloride and 1-butanol) are
 5 relatively soluble in water, and may, therefore, be expected to have contaminated soil volumes that tend
 6 to follow the water plume more closely than other VOAs.

7 **E4.3.7 PNNL 3-D Modeling and Conceptual model**

8 The results and conclusions of the PNNL studies of CT migration through the vadose zone beneath the
 9 216-Z-9 and 216-Z-1A trenches are also relevant to the assessment of the nature and extent of the
 10 contaminated soil volumes in the vadose zone at the 200-PW-1 OU (PNNL-14895; PNNL-15914; and
 11 PNNL-16198). These studies were conducted using 3-D fate and transport simulations to enhance the
 12 conceptual model of CT distribution in the vertical and lateral direction beneath the 216-Z-9 trench, and
 13 to investigate the effect of SVE on the distribution of CT in the subsurface. The simulations targeted
 14 migration of CT and co-disposed organics in the subsurface beneath the 216-Z-9 trench as a function of
 15 the properties and distribution of subsurface sediments and of the properties and disposal history of the
 16 waste. The results and conclusions of these studies provide additional insight on the spatial and temporal
 17 behavior of the contaminants in the 200-PW-1 vadose zone and the contaminant source term conceptual
 18 model. The studies also provide an independent basis for comparing and contrasting the data-based lines
 19 of evidence for the lateral extent of contamination in the vadose zone (i.e., transects, isopleths, 3-D plume
 20 depictions). The main conclusions resulting from these studies include the following:⁹

- 21 • The CT accumulates in the finer-grain sediments of the vadose zone but does not appear to pool on
 22 top of these layers.
- 23 • Migration of CT tends to be preferentially vertically downward below the disposal area, with the
 24 center of mass typically directly beneath the disposal area and within the Cold Creek unit.
- 25 • Considerable lateral movement of CT is not likely; however, significant lateral migration of vapor CT
 26 occurs.
- 27 • Lateral spreading of CT, defined as the distance between the 1 percent saturation contour planes west
 28 and east or south and north of the 216-Z-9 trench, is estimated to initially be on the order of 40 m
 29 (131 ft) in the Hanford formation, 45 m (148 ft) in the Cold Creek unit, and 60 m (197 ft) in the
 30 Ringold formation, with the expectation that CT residuals would be located in the fine-grained
 31 sediment features within this region of the vadose zone.
- 32 • Because the migration of CT is primarily in the vertical direction, CT in the groundwater would be
 33 most likely expected in a zone distributed around the centerline of the disposal area.
- 34 • Pronounced decreases occur over all CT phases (gaseous, sorbed, and aqueous phase) with SVE, and
 35 a more gradual decrease in CT DNAPL.
- 36 • Measured vadose zone soil data show low CT concentrations at distances greater than 30 m (98 ft) from
 37 the disposal areas, compared to the much higher CT concentrations vertically beneath the disposal areas.
- 38 • The spatial extent of the contaminated soil volumes for the volatile organic COPCs is smallest for the
 39 DNAPL (free product) plumes, and largest for the vapor (gas) phase plumes (e.g., Figure E4-23), and
 40 intermediate for sorbed and aqueous phase contamination SVE can effectively removes CT from the

⁹ Most conclusions focus on the CT DNAPL, but are also relevant for the vapor and aqueous phase of CT.

1 permeable layers of the vadose zone. SVE previously applied in the 216-Z-9 trench area has likely
2 removed a large portion of CT initially present in the permeable layers within the large radius of
3 influence of the extraction wells.

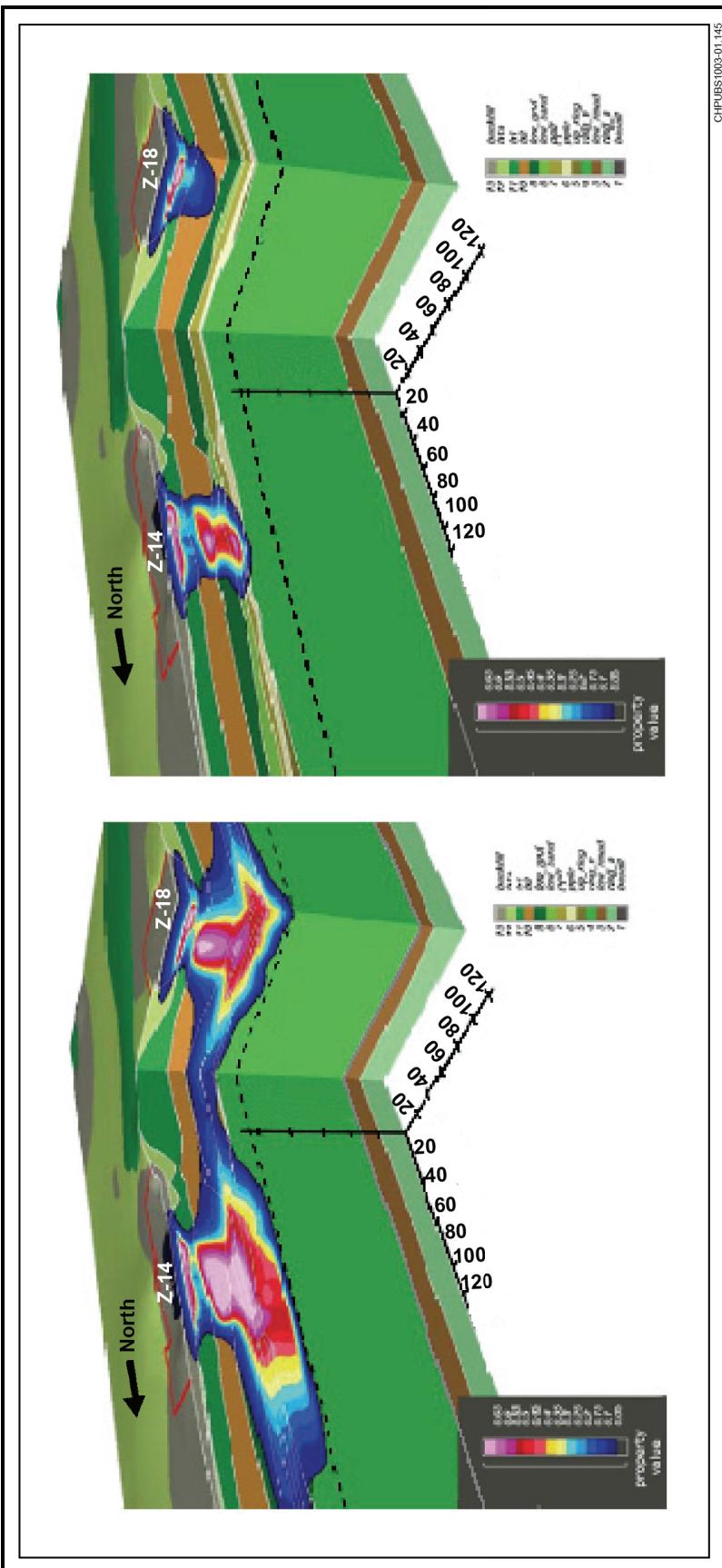
- 4 • Finer grain layers with more moisture content are less affected by SVE and contain the CT remaining
5 in the vadose zone.

6 Figures E4-23 to E4-25 illustrate many of these conclusions. Figures E4-23 and E4-24 illustrate the
7 predicted nature and extent of the CT vapor phase plumes and the CT water plume concentrations in the
8 vadose zone beneath the 216-Z-9 and 216-Z-1A Cribs over time, respectively. Figure E4-23 also shows
9 the extent of the vapor phase CT plume with and without the SVE system. The most significant features
10 and information in these figures pertaining to the nature and extent of the contaminated soil volumes in
11 the 200-PW-1 vadose zone include the following:

- 12 1. Both the vapor and aqueous (dissolved) phase plumes for CT, and by analogy, other VOA COPCs,
13 are predicted to be significantly larger than the footprint of the waste site without, and prior to,
14 operation of an SVE system, especially near the Cold Creek unit.
- 15 2. The SVE system is predicted to significantly reduce the size and concentrations of both the CT vapor
16 and aqueous phase plumes to dimensions comparable to the footprint of the waste site.
- 17 3. The residual levels of CT (and other VOAs) are predicted to be concentrated in the Cold Creek sediments.

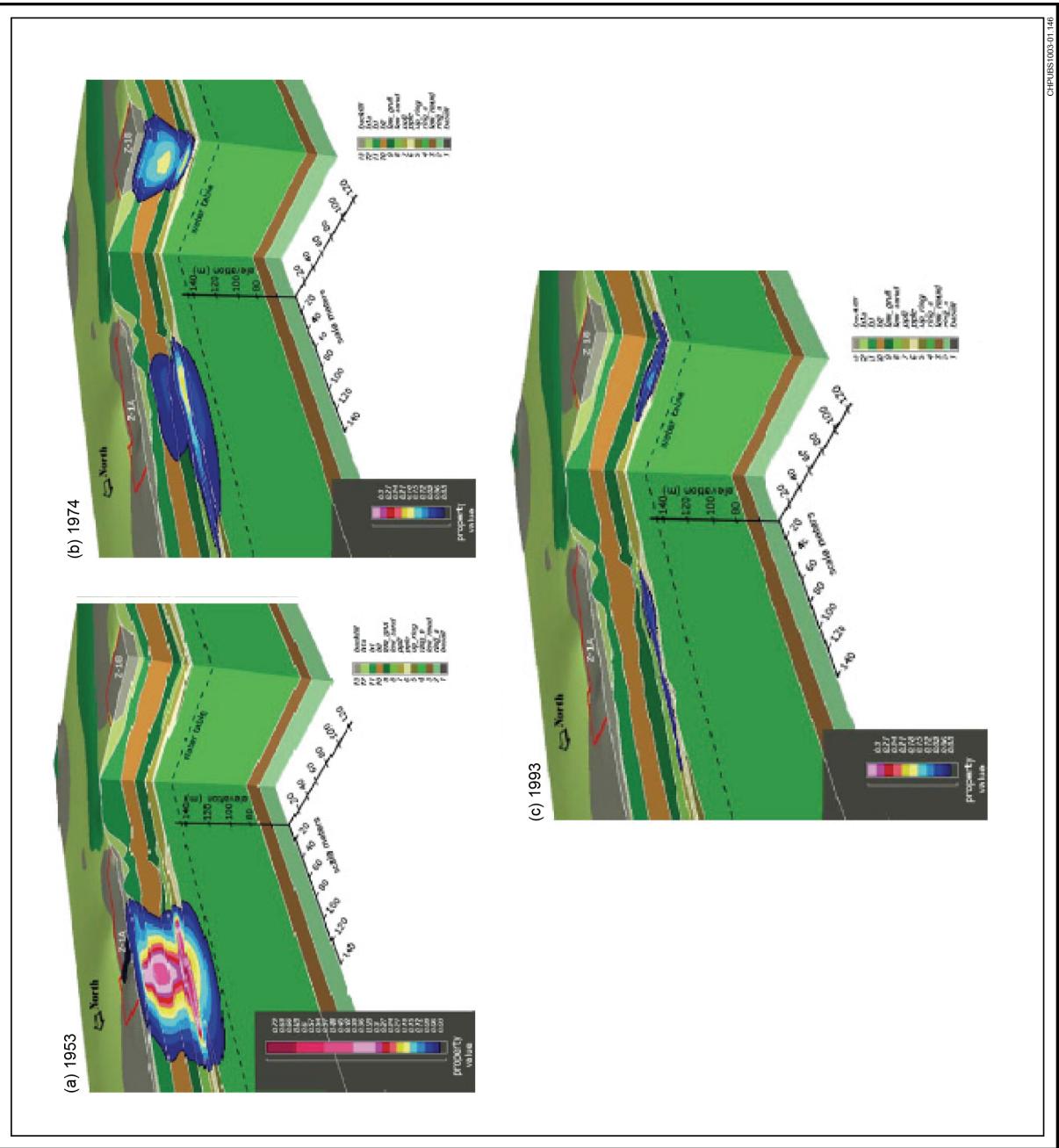
18 These features are consistent with the other data-based lines of evidence on the spatial dimensions of the
19 contaminant plumes for the VOA COPCs previously described in Section E4.3 (i.e., transect data, COPC
20 isopleths, and 3-D plume graphics). The most significant factor is that the spatial extent of vadose zone
21 contamination and the contaminant mass for the VOAs have been reduced by the SVE system based on
22 the temporal trends in soil concentrations of CT at 216-Z-9 shown in Figure E4-12, and plotted in
23 Figure E4-11. Figure E4-26 presents a summary of the predicted versus the observed reduction in CT
24 mass for the CT phases with the operation of the SVE from 1993 to 2006. It is notable that the observed
25 reductions in CT soil concentrations at 216-Z-9 closely follow the temporal trends of total mass and
26 sorbed CT predicted in the PNNL studies. Although the focus of the PNNL studies was on CT, it is
27 logical to presume that essentially all VOAs with comparable physical and chemical properties to CT, as
28 discussed in Section E4.3.4, would be similarly affected by the SVE system, and, therefore, have
29 contaminated soil volumes with spatial and temporal patterns similar to that of CT. This appears to be
30 corroborated by the isopleths data shown for methylene chloride, tetrachloroethene, and 1-butanol in
31 Section E4.3.2, and lateral dimensions of the contaminated soil volumes of the VOA COPCs since 2006
32 as comparable to those of the waste site footprint. It is also likely that the contaminated vadose zone soil
33 plume dimensions are presently (year 2010) even smaller due to the additional time of SVE operation
34 since the last soil sampling efforts in 2006.

35

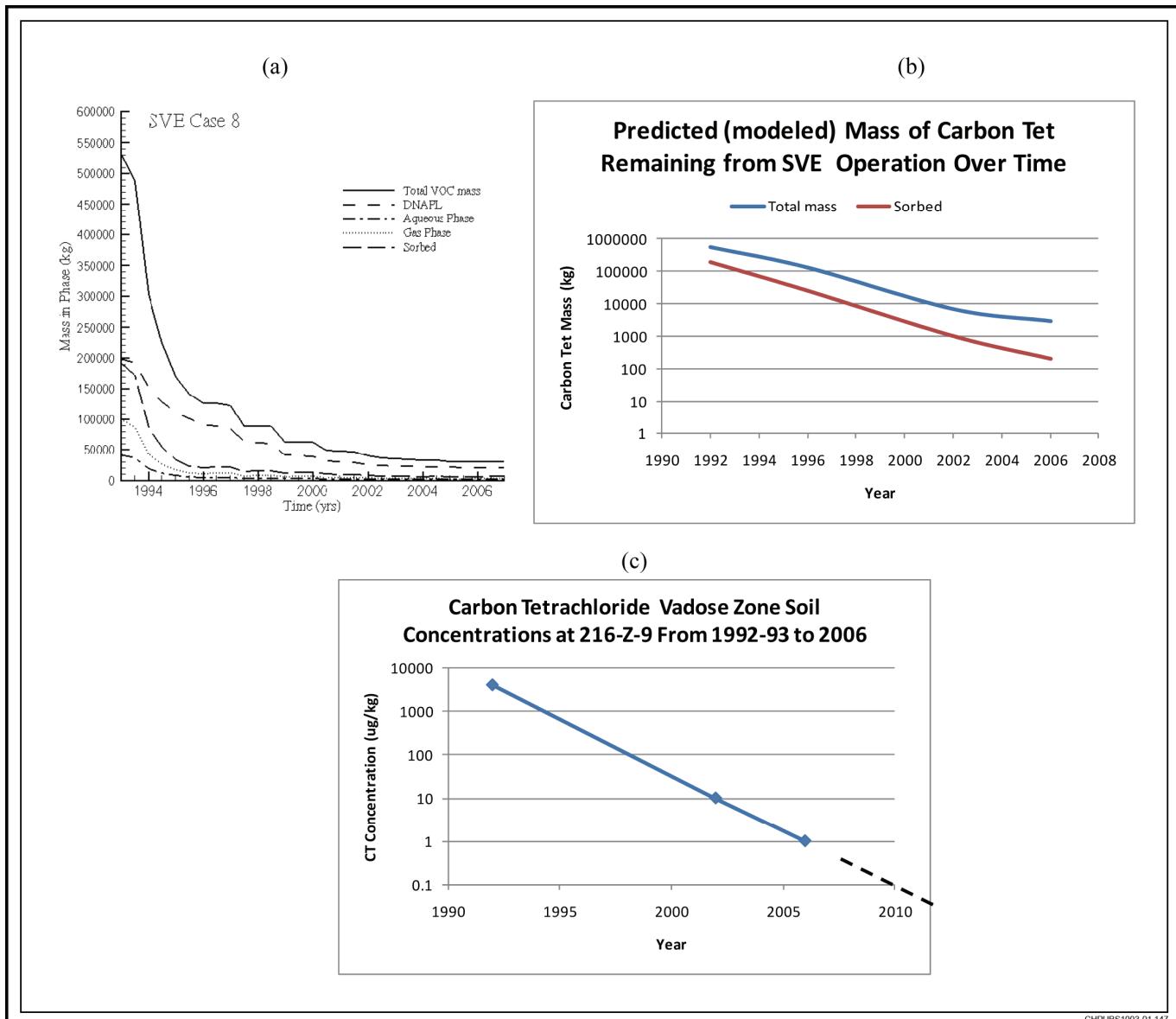


- 1
2 a) CT Gas Concentrations (g/L) at 1995 (Base Case)*
3 *0.1 g/L is equivalent to 12,000 ppmv at standard temperature and pressure. Higher CT concentrations shown in red, lower concentrations shown in dark blue
4 Conceptual spatial distribution of CT are from the 3-D model Base Cases reported in PNNL-16198, Carbon Tetrachloride Flow and Transport in the Subsurface of the
5 216-Z-18 Crib and 216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update.

6 **Figure E4-23. Comparison of Conceptual Vapor Phase (gas) CT Concentrations in (a) Year 1995 Without SVE, and (b) Year 2000 with SVE**



Note: Higher CT concentrations shown in red; lower CT concentrations shown in dark blue
Figure E4-24. Predicted (Modeled) Differences in CT Water Saturations Between the 1948 (Base Case) and CT Water Saturations



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Figure E4-25. (a) PNNL Predicted CT Mass Distribution over the DNAPL, Sorbed, Aqueous, and Gas Phases for 1993 - 2007 (SVE Case 8); (b) Plot of the Predicted (Modeled) Decreases in Total and Sorbed Mass of CT over Time from the Results Shown in (a); (c) Plot of Observed Average CT Concentrations for the Depth Interval 15 to 37 m (50 to 120 ft) bgs from the CT Isopleths over Time in Figure E4-12

1 This information also has relevance for evaluation of the nature and extent of mobile non-VOA COPCs
 2 such as nitrogen (as nitrate+nitrite). Although mobile non-VOA contaminants are assumed to be
 3 essentially unaffected by the SVE system, the spatial distribution 3-D modeling of the water-soluble
 4 concentrations (dissolved CT plume) of a relatively mobile COPC such as CT, may be a reasonable
 5 approximation for the spatial distribution of mobile contaminants, such as nitrate. This may be because
 6 COPCs with small K_d values tend to follow the spatial distribution of the water plume. This conclusion
 7 also appears to be corroborated by the estimated dimension of the contaminated soil volume for nitrogen
 8 shown in Figures E4-17, E4-20, and Figure E4-21 as approximately two times the footprint dimensions of
 9 the waste site. Based on this logic, it is also likely that the lateral dimensions of the contaminated soil
 10 volumes for other non-VOA COPCs such as Tc-99 may be comparable to that of the nitrogen plume. For
 11 contaminants such as Tc-99 that occur primarily concentrated in the Hanford formation rather than the
 12 Cold Creek unit where lateral spreading appears to be greater, the lateral dimensions of the contaminated
 13 soil volume may also be smaller than that of the nitrogen plume.

14 **E4.3.8 Dimensions of Contaminated Soil Volumes for Vadose Zone Fate and Transport Modeling**

15 The lateral dimensions were also defined by using specified length dimensions based on the evaluations
 16 of the lateral extent of the contaminated soil volumes described in Section E4.3. The vertical (thickness)
 17 dimensions of the contaminated soil volumes used to describe the source terms in the fate and transport
 18 modeling were defined by assigning the depth intervals of the vadose zone contamination for each of the
 19 waste sites in Table E4-1 to the corresponding parts of the domain stratigraphy. As described in
 20 Section E4.2.4, three approaches to defining contaminant source term volumes were used to best
 21 represent the vertical distribution of contaminants in the vadose zone:

- 22 • Rectangular-shaped contaminated soil volumes for specific depth intervals
- 23 • Irregularly shaped contamination volumes where contamination is assumed to occur throughout a
 24 geologic unit with variable thickness
- 25 • Contaminated source terms described as unit-thickness volumes, referred to as point source volumes

26 All three approaches for describing the contaminated soil volume source term configurations for the fate
 27 and transport modeling base cases. The identification of discrete depth intervals for the contaminated soil
 28 volumes allows the pooling of COPC data within the intervals to describe the population of soil
 29 contamination data, from which soil concentrations for the intervals can be calculated. The dimensions of
 30 the contaminated soil volumes used in the modeling is illustrated in Figures E4-26, E4-27 and E4-28 for
 31 the vadose zone beneath the 216-A-8, 216-Z-1A and 216-Z-18, and 216-Z-9 waste sites, respectively.

32 The contaminated soil source term volumes for the 216-A-8 Crib are described as 1 m (3.2 ft) thick point
 33 source volumes in Figure E4-25 because the COPC data above screening levels primarily occur at only
 34 single depths as described in Section E4.2.4. The contaminated soil volumes within the Hanford
 35 formation and Ringold units beneath the 216-Z-1A, 216-Z-18, and 216-Z-9 Cribs, were described as
 36 essentially horizontal rectangular-shaped volumes with the thicknesses specified in Table E4-1, and
 37 shown in Figures E4-26 to E4-28. The contaminated soil volumes within the upper and lower facies of the
 38 Cold Creek formation at the 216-Z-1A and 216-Z-9 Cribs are based on the integrated area of the
 39 irregularly shaped upper and lower depth interval boundaries in the E-W cross-section shown in
 40 Figures E4-27 and E4-28.

41 The lateral dimensions of the contaminated soil volumes (parallel to the direction of groundwater flow)
 42 were based on the dimensions of the waste site footprint. Volumes based on the lateral dimensions of 1× and
 43 2× the length of the waste site footprint parallel to the direction of groundwater flow were evaluated as base
 44 cases for most waste sites. Lateral dimensions of 1×, 0.5×, and 0.25× the length of the waste site footprint

parallel to the direction of groundwater flow were evaluated for the contaminated soil volumes at the 216-A-8 Crib. This approach allowed for flexibility in the interpretation of the model results for various COPCs in the context of the evaluation of the spatial relationships of the contaminated soil volumes presented in Section E4.3. Based on the results of the various lines of evidence presented in Section E4.3, it is indicated that the lateral dimensions of the COPC plumes in the vadose zone is estimated to be about $\leq 2 \times$ the dimension of the waste site footprint for mobile non-VOA COPCs, and $\leq 1 \times$ the dimension of the waste site footprint for the VOAs. The use of lateral dimensions $\leq 1 \times$ the dimension of the waste site footprint for the contaminated soil volumes of the less mobile COPCs is assumed to be a conservative assumption based on the contaminant behavior conceptual model. The calculation of all contaminated soil volumes were based on a width dimension of 1 m (3.2 ft) for the calculation of the COPC mass per meter width normal to the direction of groundwater flow (see Sections E4.1 and E5.4). Details on the assignment of contaminated soil volume source terms, and sensitivity cases evaluated are described in ECF-200PW1/3/6-10-0326. Sections E4.6 and E5.6 discuss associated uncertainties.

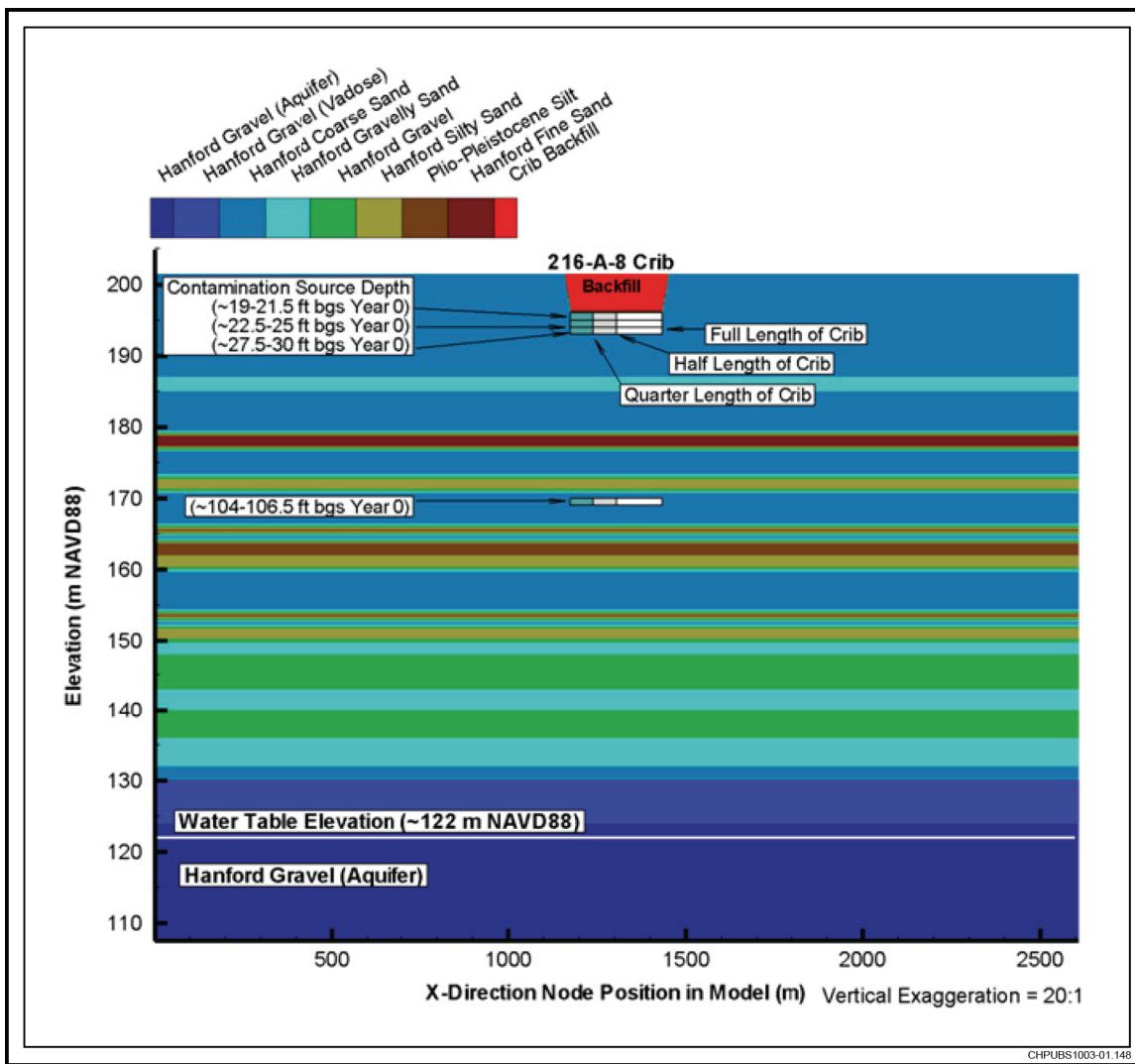
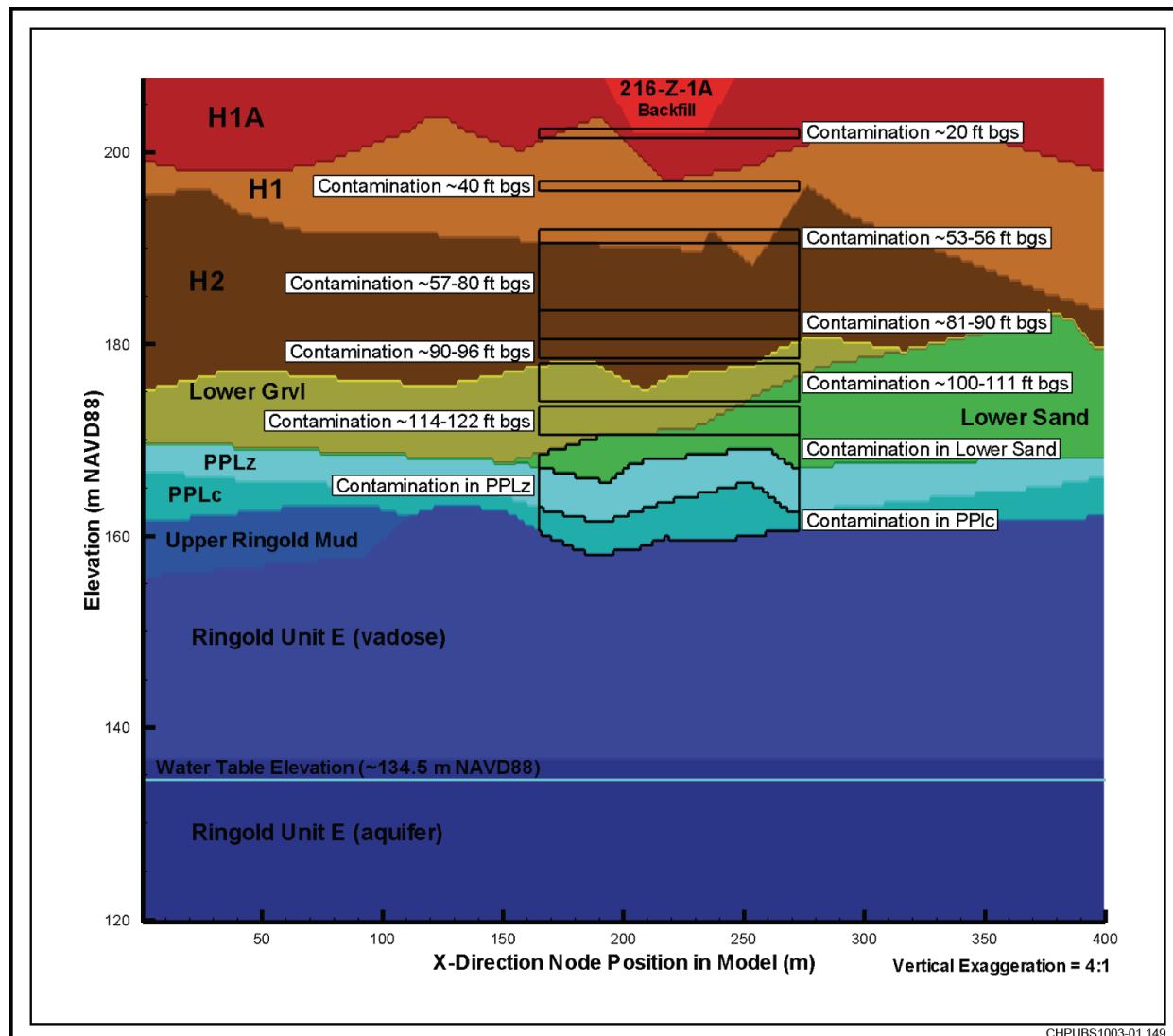
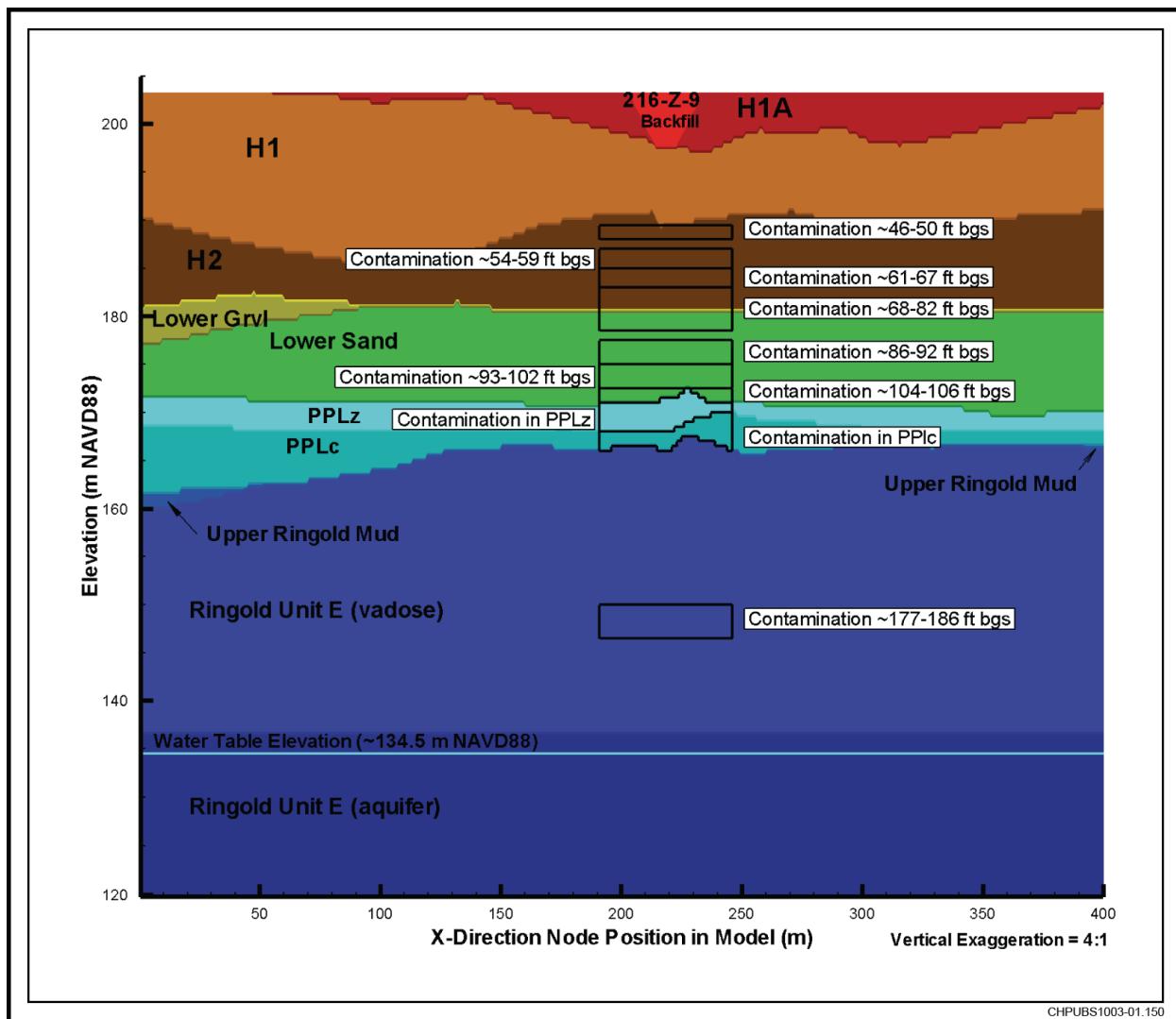


Figure E4-26. Locations and Distribution of Contaminated Soil Volume Source Terms Used in the 216-A-8 Crib Contaminant Fate and Transport Analysis



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Figure E4-27. Locations and Distribution of Contaminated Soil Volume Source Terms
Used in the 216-Z-1A Crib Contaminant Fate and Transport Analysis



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Figure E4-28. Locations and Distribution of Contaminated Soil Volume Source Terms
Used in the 216-Z-9 Crib Contaminant Fate and Transport Analysis

1 **E4.3.9 Calculation of Contaminated Soil Volume Concentrations**

2 The estimation of COPC soil concentrations for the contaminated soil volumes serve as the source term
 3 inputs to vadose zone fate and transport modeling. This section describes the rationale and process for the
 4 estimation of the concentration terms for the contaminated soil volumes at the 216-A-8, 216-A-1A,
 5 216-Z-18, and 216-Z-9 waste sites described in Section E4.4.

6 At each waste site, soil concentrations were calculated for each contaminated soil volume depth interval
 7 for each COPC passing the Phase I and Phase II screening, containing one or more data values above the
 8 screening levels. In most cases, all of the data for a COPC evaluated within a depth interval were pooled
 9 and treated as a data population for calculating concentrations intended to represent the contaminated soil
 10 volume in the modeling.¹⁰ Thus, soil concentrations were only calculated for COPCs passing all
 11 screening criteria, and generally only in depth intervals where all of the data were not all non-detect
 12 values ("U" coded data), or not all less than the COPC screening levels described in Chapter E2.0.

13 Summary statistics were calculated from the population of data for each depth interval evaluated. The
 14 calculated summary statistics include the maximum, average, 90th percentile, 95 percent upper
 15 confidence limit (UCL) concentration values, and number of samples (n value) for each depth interval.
 16 Tables E4-3 to E4-6 summarize the data sets and summary statistics for the data set for each COPC
 17 evaluated in each depth interval for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 waste sites,
 18 respectively. Data distribution types were identified for data sets with four or more data values ($n \geq 4$), and
 19 the summary statistical values (e.g., mean, 90th percentile values, and 95 percent UCL values) were
 20 calculated accordingly. For data sets with two values ($n=2$), the 90th percentile values were calculated as
 21 $v_1 + 0.9*(v_2-v_1)$, where v_1 and v_2 equal the minimum and maximum value, respectively. For data sets with
 22 three values ($n=3$), the 90th percentile values were calculated as $v_2 + 0.8*(v_3-v_2)$, where v_2 and v_3 equal
 23 the median and maximum values of the data set, respectively.

24 Some summary statistical values (e.g., percentiles, UCLs) were not calculated where the numbers of
 25 sample were insufficient to provide meaningful values. In those cases, only the numbers of samples,
 26 maximum and average values are reported. Where the calculated values of the mean, 90th percentile, and
 27 95 percent UCL values were all less than the COPC screening levels, the values in Tables E4-3 to E4-6
 28 were highlighted and deemed inconsequential. This occurred for depth intervals in which there were
 29 many more low, and/or non-detect data values, than data values above the screening criteria. The 90th
 30 percentile and 95 percent UCL summary statistic values larger than the maximum value are also
 31 highlighted and/or censored in the Tables E4-3 to E4-6 because they are not meaningful values.

32 The calculated soil concentration values for each COPC evaluated within each depth interval, based on
 33 the mean, 90th percentile, and 95 percent UCL values, were all evaluated in the fate and transport
 34 modeling to provide a statistical basis for the evaluation of model results and associated groundwater
 35 impacts (Chapter E5.0). The use of these statistical values for source term concentration in the modeling
 36 was intended to provide a basis for assignment of the source term concentration that can reduce some
 37 uncertainties associated with the estimation of source term concentrations for a depth interval, versus the
 38 use of e.g., maximum or average values alone. This approach was also intended to provide a basis for
 39 evaluating the magnitude and direction of the source term uncertainty in the context of the overall
 40 uncertainty in the modeling results. It is notable that the calculated 95 percent UCL values for many of
 41 depth intervals differ only moderately from the mean values, especially where the population of COPC

¹⁰ In some cases, a value of zero was assigned to data values where reported values below detection limits exceeded the values of data above detection limits, to avoid the generation of summary statistics for soil concentrations dominated by data below detection rather than data above detection.

1 values includes a relatively large proportion of small and/or non-detect values together with a smaller
2 number of larger values.

3 **E4.3.10 Summary Statistic Calculation QA/QC**

4 Summary statistics were calculated from the population of data for each depth interval evaluated using
5 Microsoft Excel® statistical functions and the EPA ProUCL software, Version 4.0.4. The summary
6 statistical values (e.g., mean, 90th percentile values, and 95 percent UCL values) for data sets with four or
7 more data values ($n \geq 4$) were calculated using the ProUCL software to utilize the capability of the
8 ProUCL software to identify data distribution types, and to calculate 95 percent UCL values accordingly.
9 For data sets with only two or three values ($n=2$ or 3), the 90th percentile values were calculated using
10 Microsoft Excel statistical functions that implement the methods described in Section E4.3.9.

11 Because the input data, mathematical formulas, and calculations used in the Microsoft Excel and ProUCL
12 spreadsheets are wholly incorporated into the documentation and can be exactly verified, these
13 spreadsheet tools are exempt from the requirements of contractor-approved internal work requirements
14 and processes.

15 **E4.4 Comparison of Methods for Estimating Representative Concentrations of
16 Contaminated Soil Volumes**

17 One of the largest sources of uncertainty in the results of the fate and transport modeling is associated
18 with the calculation of the contaminant source term mass, which is based on the estimated values for the
19 contaminated soil volumes and the contaminant concentrations. The contaminant concentration term
20 appears to be the largest source of uncertainty in the source term definition for the 200-PW-1/3/6
21 modeling. The COPC concentration values assigned to a contaminated soil volume are intended to
22 represent the integrated range of concentrations throughout the volume, i.e., the average composition.
23 Contaminant masses are determined from these concentration values in the fate and transport models
24 based on the relationships described in Equation E4-1, and are used as the source term in the evaluation of
25 groundwater impacts. The source term mass is an especially significant parameter in the fate and transport
26 modeling because the modeled groundwater concentrations are proportional to the source term mass. The
27 capability of the model to yield meaningful results depends to a large extent on how well the estimates of
28 the source term concentrations represent those that actually occur in the natural system, and the
29 uncertainty associated with the estimation of the source term concentration. This significant factor must
30 be considered in the interpretation of model results and associated risk management decisions, because
31 the largest source of uncertainty is often associated with the source term definition involving estimation
32 of contaminated soil volumes and representative COPC soil concentrations, and/or associated
33 assumptions. Therefore, an assessment of the assumptions and uncertainties associated with the source
34 term definition for the 200-PW-1/3/6 modeling is warranted. The following is a discussion of the key
35 uncertainty factors associated with the estimation of the contaminated soil volumes and concentrations for
36 the 200-PW-1/3/6 modeling.

37

Table E4-3. 216-Z-1A Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-1A COPCs	1,1-Dichloroethane				Chloroform				Carbon Tetrachloride										
	Depth Interval/ Soil Volume	57-80	100-111	Cold Creek Silt	57-80	114-122	Hanford L. Sand	Cold Creek Silt	20	40	53-56	57-80	81-90	90-96	100-111	114-122	Hanford L. Sand	Cold Creek Silt	Cold Creek Carb
Screening Level	0.0419				0.00751				0.00310						mg/kg				
Concentration Units																			
Soil Concentration Data	0	0	0	0	0.003	0	0.012	0.135	0.003	0.026	0.031	0.133	0.056	0.018	0.016	0.024	0.789	0.317	0.772
	0	0	0	0	0	0	0.019	0.012	0.028	0.075	0.051	0.006	0.003	0.103	1.247	1.093			
	0	0	0	0	0.008	0	0	0	0.041	0.143	0.095	0.013	0.002	0.246	0.796	0.051			
	0	0	0	0.006	0	0	0	0	0.095	0.126	0.099	0.015	0.061	0.498	0.89	0.644			
	0	0	0	0.076	0	0	0	0	0.083	0.035	0.044	0.003	0.05	0.072	0.261	0.261			
	0	0	0	0	0	0	0	0.038	0.126	0.06	0.013	0	0.034	0.749					
	0.1	0	0	0	0.031	0	0	0	0.36	0.074	0.019	0.035	0.035	0.23	0.045				
	0	0	0	0	0	0	0.12	0.069	0.069	0.019	0.116	0.068	0.01	0.037	6.561				
	0	0	0	0	0	0	0.063	0.15	0.147	0.063	4.124								
	0.075	0	0	0.003	0.021	0	0.095	0.052	0.052	0.032	0.024	0.024	0.024	0.024	0.024				
	0	0	0	0	0	0	0	0	0.349	0.349	0.151	0.026	0.026	0.026	0.026	0.026			
	0	0	0	0	0.02	0	0.05	0.05	0.374	0.374	0.427	0.427	0.337	0.337	0.337	0.337			
	0	0	0	0	0	0	0.04	0.04	0.151	0.151	0.357	0.357	0.115	0.115	0.115	0.115			
	0	0	0	0	0	0	0.085	0.085	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067			
	0	0	0	0	0.006	0	0.005	0	0.137	0.137									
	0	0	0	0	0	0	0	0											
n	18	12	5	18	15	12	5	1	1	4	18	7	7	9	15	12	5	1	
min	0	0	0	0	0	0	0	0.003	0.026	0.028	0.052	0.035	0.006	0	0.024	0.051	0.051	0.772	
max	0.100	0.003	0.076	0.031	0.085	0.12	0.135	0.0030	0.0260	0.0950	0.360	0.099	0.044	0.116	0.498	6.561	1.093	0.772	
avg	0.0097	0.0003	0.0164	0.0052	0.0083	0.0331	0.0300	0.0030	0.0260	0.0488	0.1493	0.0671	0.0183	0.0273	0.1477	1.5633	0.4732	0.7720	
90th Percentile	0.0225	0.0000	0.0410	0.0203	0.0200	0.0886	0.0735	-	-	0.0734	0.3390	0.0962	0.0265	0.0665	0.3920	3.9170	0.8690	0.7720	
95% UCL	0.0215	0.0007	0.0483	0.0090	0.0191	0.0545	0.0862	-	-	0.0856	0.2000	0.0844	0.0272	0.0514	0.2530	3.5310	0.8610		

Table E4-3. 216-Z-1A Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-1A COPCs	Methylene Chloride						Tetrachloroethene (PCE)						Trichloroethene (TCE)						Nitrogen (Nitrate+Nitrite)		
	40	57-80	81-90	90-96	100-111	114-122	57-80	81-90	100-111	114-122	Hanford L. Sand	Cold Creek Silt	57-80	81-90	100-111	114-122	Hanford L. Sand	Cold Creek Silt	53-56	81-90	
Screening Level	0.0223												0.0223							9.03	
Concentration Units	mg/kg						mg/kg						mg/kg						mg/kg		
Soil Concentration Data	4.679	0	0	0	0.194	0	0	0	0	0	0	0	0.047	0.001	0	0.002	0	0	0.061	56.5	0.5
	0	0	0	0	0	0	0	0	0	0	0	0	0.008	0	0	0	0	0	0	0.003	121.7
	1.062	0	0.181	0	0	0	0.005	0.005	0	0	0	0	0	0	0	0	0	0	0	0	0.54
	0	0	1.858	0	0	0.113	0.004	0	0.006	0.003	0	0	0	0.004	0.006	0.003	0	0	0	0	487
	0	0	0	0	0	0.007	0	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0.003
	2.264	0	0	0	0	0	0.021	0.002	0.003	0	0	0	0.024	0	0	0	0	0	0	0.031	0
	0	0.1116	0.153	0	0	0	0	0	0	0	0	0	0.029	0	0.03	0.002	0.005	0	0	0	0.002
	0	0	0	0	0	0	0	0	0	0	0	0	0.033	0	0	0.004	0	0	0	0.041	0
	0.771	0	0	0	0	0	0	0	0	0.004	0	0	0.021	0	0	0	0	0	0	0	0.042
	0	0	0.122	0.01	0	0.578	0	0	0	0.002	0.005	0	0	0	0	0	0	0	0	0	0.068
	0	0	0	0	0	0	0.004	0	0	0	0	0.034	0	0	0	0	0	0	0	0	0.044
	0.538	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0.004	0	0	0.003	0	0.003	0	0	0.004	0	0	0	0	0	0
	0	0	0	0	0	0	0.003	0	0	0.003	0	0.003	0	0	0.004	0	0	0	0	0	0
	0	0	0	0	0	0	0.005	0	0.005	0	0	0	0	0	0.004	0	0	0	0	0	0
n	1	17	7	3	8	15	18	7	9	15	12	5	18	7	9	15	12	5	1	4	
min	4.68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56.5	0.5
max	4.68	2.264	0.116	0.181	1.858	0.578	0.021	0.006	0.004	0.002	0.05	0.047	0.03	0.006	0.005	0.003	0.068	0.061	56.5	487	
avg	4.68	0.2726	0.0166	0.0603	0.276	0.0542	0.0039	0.0019	0.0011	0.0003	0.0148	0.0094	0.0036	0.0019	0.0016	0.0003	0.0190	0.0134	56.5	152	
90th Percentile	4.68	0.8580	0.0348	0.145	0.527	0.118	0.0076	0.0053	0.0031	0.0010	0.0338	0.0235	0.0074	0.0053	0.0041	0.0010	0.0436	0.0320	56.5	341	
95% UCL	-	0.5290	0.0488	-	0.707	0.123	0.0061	0.0038	0.0022	0.0006	0.0242	0.0294	0.0070	0.0038	0.0028	0.0007	0.0317	0.0388	-	423	

Note: Values reported only where calculable (n>3), and not greater than the maximum value.

Values in red denote values less than detection or less than the screening level, but used in the calculation of summary statistics. Summary statistics shaded in gray denote values less than the COPC screening level.

Table E4-4. 216-Z-18 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-18 COPCs	Benzene	Carbon Tetrachloride										Chloroform				Ethylbenzene									
		40	20	40	53-56	57-80	81-90	90-96	100-111	114-122	Hanford L. Sand	Cold Creek Silt	Cold Creek Carb	81-90	100-111	Hanford L. Sand	Cold Creek Silt								
Depth Interval/ Soil Volume		Screening Level										0.0344													
Concentration Units	mg/kg	Concentration										mg/kg				mg/kg									
Soil Concentration Data										0.004	0.006	0.009	0.122	0.139	0.099	0.111	0.034	0.041	1.618	0	0	0	0.027	0.027	
										0	0.006	0.015	0.039	0.089	0.056	0.193	0.012	0.052	0.111	0	0	0	0.061	0.061	
										0	0.007	0.024	0.031	0.133	0.188	0.168	0.006	0.009	0.017	0.002	0	0	0.023	0.023	
										0.004	0.013	0.074	0.079	0.124	0.053	0.028	0.041	0.134	0	0	0	0	0	0	
										0.011	0.011	0.216	0.093	0	0.007	0.068	0.068	0.717	0	0	0	0	0	0.004	0.004
										0	0	0.184	0.566	0.004	0	0.005	0.005	0.786	0.016	0	0	0	0	0.007	0.007
										0	0	0	0.332	0.242	0.008	0.759	0.021	0	0	0	0	0	0	0.005	0.005
										0	0	0.44	0.44	0.127	0.058	0.334	0.334	0.004	0.004	0	0	0	0	0.018	0.018
										0	0	0.14	0.14	0.065	0.494	0.494	0.494	0.004	0.004	0	0	0	0	0.004	0.004
										0	0	0.014	0.014	0.043	0.481	0.481	0.481	0.004	0.004	0	0	0	0	0.004	0.004
										0	0	0.044	0.044	0.028	0.861	0.861	0.861	0.005	0.005	0	0	0	0	0.005	0.005
										0	0	0.01	0.01	0.039	0.714	0.714	0.714	0.004	0.004	0	0	0	0	0.004	0.004
										0	0	0.004	0.004	0.016	0.626	0.626	0.626	0.004	0.004	0	0	0	0	0.004	0.004
										0	0	0.017	0.017	0.014	0.024	0.024	0.024	0.003	0.003	0	0	0	0	0.003	0.003
										0	0	0.004	0.004	0.028	0.028	0.028	0.028	0.008	0.008	0	0	0	0	0.008	0.008
										0	0	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957	1.957
n		11	1	3	4	6	8	4	14	6	16	16	16	16	16	16	16	16	16	16	16	16	16	2	2
min		0	0.004	0.006	0.009	0.031	0.079	0.056	0	0	0.004	0.017	0	0	0	0	0	0	0	0	0	0	0	0.0270	0.0270
max		0.011	0.004	0.0070	0.024	0.216	0.566	0.188	0.242	0.034	0.068	1.957	0.002	0.023	0.018	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.0610	0.0610
avg		0.0014	0.0040	0.0063	0.0153	0.1110	0.2339	0.1168	0.0805	0.0145	0.0310	0.6038	0.0004	0.0051	0.0021	0.0011	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0440	0.0440
90th Percentile		0.0036	0.0040	0.0068	0.0213	0.1970	0.4650	0.1620	0.1830	0.0304	0.0608	1.1640	0.00100	0.0170	0.00000	0.00000	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	0.0074	0.0576	0.0576
95% UCL		0.0032	-	-	0.0227	0.1740	0.4230	0.1820	0.1190	0.0256	0.0409	1.0450	0.0125	0.0108	0.0059	0.0031	0.0109	0.0109	0.0109	0.0109	0.0109	0.0109	0.0109	-	-

Table E4-4. 216-Z-18 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-18 COPCs		Methylene Chloride										Tetrachloroethene (PCE)				Nitrogen (nitrate+nitrite)		
Depth Interval/ Soil Volume	20	40	53-56	57-80	81-90	90-96	100-111	114-122	Hanford L. Sand	Cold Creek Silt	57-80	90-96	100-111	Hanford L. Sand	Cold Creek Silt	81-90	100-111	
Screening Level																9.03		
Concentration Units	mg/kg										mg/kg				mg/kg			
Soil Concentration Data	0.134	0	1.992	0	10.98	0	0	1.325	0	1.612	0	0	0	0	0.033	1.603	0.926	
	0.08	0	0.237	0	0	0	0	0	0	0	0	0	0	0	0.033	994	223.5	
	0	0	0.056	0.125	1.108	0.559	90.0	0	0	0	0	0	0	0	0.006	0	1.755	
			0.272	0	0	0	0	0	0	0.061	0.079	0	0	0	0.047			
			0	0.126	0	0	0	0	0	0	0	0	0	0	0.0003			
			0	0	0.083	0	0	0	0	0	0	0	0	0	0.002			
				0	0	0	0	0	0	0.085	0	0	0	0	0.002			
				0	0	0	0	0	0	88.8	0	0	0	0	0	0.002		
					0	0	0	0	0	0	0	0	0	0	0	0		
						0	0	0	0	0	27.7	0	0	0	0	0		
						0	0	0	0	0	0.089	0	0	0	0	0		
						0	0	0	0	0	0	0	0	0	0	0		
						0	0	0	0	0	0	0	0	0	0	0		
						0	0	0	0	0	0.182	0	0	0	0	0		
						0	0	0	0	0	1.613	0	0	0	0	0		
n	3	5	3	6	8	4	13	7	16	15	6	4	10	16	5	2	2	
min	0	0	0.0560	0	0	0	0	0	0	0	0	0	0	0	0.0003	1.60	0.93	
max	0.134	0.272	1.99	0.126	11.0	0.559	90.0	1.325	88.8	27.7	0.0020	0.0050	0.0060	0.0020	1.76	994	224	
avg	0.0713	0.0544	0.762	0.0418	1.52	0.140	6.93	0.189	5.57	2.07	0.0003	0.00125	0.0010	0.000125	0.374	498	112	
90 th Percentile	0.123	0.136	1.641	0.125	3.08	0.335	0.0623	0.398	0.124	1.61	0.0008	0.0030	0.0020	0.0000	0.901	894	201	
95%UCL	-	0.170	-	0.0951	4.10	0.469	19.3	0.557	15.3	5.31	0.0010	0.0042	0.0021	0.00034	1.11	-	-	

Note: Values reported only where calculable ($n > 3$), and not greater than the maximum value.

Values in red denote values less than detection or less than the screening level, but used in the calculation of summary statistics. Summary statistics shaded in gray denote values less than the COPC screening level.

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	1,1,2,2-Tetra-chloroethane		1,1,2-Tri-chloroethane	1-Butanol			Bromodi-chloromethane	Bromoform
Depth Interval/ Soil Volume	54-59	61-67	61-67	54-59	61-67	86-92	61-67	61-67
Screening Level	0.00123		0.00427	3.31			0.00368	0.0363
Concentration Units	mg/kg		mg/kg	mg/kg			mg/kg	mg/kg
Soil Concentration Data	0.015	0.0003	0.00029	0.0035	0	0.0036	0.000134	0.0002
	0.0038	0.0051	0.0003	0.075	0.0037	0.0037	0.00014	0.00025
	0.014		0.0003	4	0.0037	0.0762	0.000141	0.00026
	0.017		0.00031		0.0039	0.26	0.00018	0.00026
			0.00031		0.034	2.5	0.00034	0.00026
			0.00031		0.14	3.2	0.00035	0.00026
			0.00031		0.43	3.8	0.00035	0.00027
			0.00032		4	4.2	0.00036	0.00027
			0.00032		5.7	4.4	0.00036	0.00027
			0.000364			5	0.00036	0.00027
			0.000382				0.00037	0.00028
			0.0005				0.00037	0.000345
			0.00063				0.00038	0.000362
			0.019				0.012	0.051
			0.057				0.031	0.06
			0.067				0.037	0.12
n	2	4	16	3	9	10	16	16
min	0.004	0.000	0.000	0.004	0.000	0.004	0.000	0.000
max	0.015	0.017	0.067	4.0	5.7	5.0	0.0370	0.120
avg	0.0094	0.0091	0.00923	1.36	1.15	2.34	0.0052	0.0147
90th Percentile	0.0139	0.0158	0.0342	3.22	4.17	4.40	0.0196	0.0546
95% UCL	-	-	0.0185	-	2.48	3.54	0.0103	0.0295

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Carbon Tetrachloride								
Depth Interval/ Soil Volume	46-50	54-59	61-67	68-82	86-92	93-102	102-106	Cold Creek Silt	Cold Creek Carb
Screening Level	0.0031								
Concentration Units	mg/kg								
Soil Concentration Data	0.0003	0.0009	0.0003	0.0009	0.0002	0.0008	0.0003	0.00016	0.00016
	0.001	0.001	0.0003	0.0009	0.0002	0.0009	0.0007	0.001	0.00052
	0.014	0.27	0.0009	0.0009	0.0002	0.001	0.0007	0.0011	0.00078
		2.6	0.001	0.001	0.0009	0.001	0.0008	0.0011	
			0.001	0.001	0.001	0.0036	0.001	0.0011	
			0.001	0.001	0.001	0.005	0.001	0.002	
			0.001	0.001	0.005	0.02	0.001	0.0021	
			0.001	0.013	0.019	0.15	0.001	0.003	
			0.001		0.057	0.47	0.001	0.005	
			0.001		0.058		0.001	0.005	
			0.001		0.059		0.001	0.009	
			0.035				0.001	0.092	
			0.52				0.001	0.14	
			0.75				0.0011	0.19	
			1.5				0.0011	0.24	
			380				0.0012		
			390				0.0019		
							0.0042		
							0.005		
							0.005		
							0.0051		
							0.006		
							0.006		
							0.006		
							0.006		
							0.006		
							0.006		

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Carbon Tetrachloride								
Depth Interval/ Soil Volume	46-50	54-59	61-67	68-82	86-92	93-102	102-106	Cold Creek Silt	Cold Creek Carb
Screening Level	0.0031								
Concentration Units	mg/kg								
n	3	4	17	8	11	9	43	15	3
min	0.000	0.001	0.000	0.001	0.000	0.001	0.000	0.000	0.000
max	0.014	2.6	390	0.013	0.059	0.470	6.30	0.240	0.00078
avg	0.0051	0.718	45.5	0.0025	0.0183	0.0725	0.329	0.046	0.0005
90th Percentile	0.0114	1.67	115	0.0034	0.0579	0.182	0.281	0.165	0.0007
95%UCL	-	2.20	99.6	0.0053	0.0326	0.170	0.620	0.0826	-

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Chloroform						Methylene Chloride
Depth Interval/ Soil Volume	46-50	54-59	61-67	102-106	Cold Creek Silt	Cold Creek Carb	Cold Creek Silt
Screening Level	0.00751						0.0218
Concentration Units	mg/kg						mg/kg
Soil Concentration Data	0.0002	0.0001	0.0002	0.0002	0.00016	0	0
	0.0002	0.0002	0.0002	0.0002	0.00017	0	0
	0.016	0.0002	0.0002	0.0002	0.00024	0.00034	0
	0.11	0.0002	0.0003	0.0002	0.0012	0.000342	0
		0.0002	0.0031	0.0002	0.0014	0.00093	0
		0.0002	0.0036	0.0002	0.0021	0.0011	0
		0.0002	0.006	0.0002	0.003	0.0012	0
		0.0002	0.0093	0.0002	0.005	0.0019	0
		0.0002	0.024	0.0002	0.005	0.0026	0
			0.0002	0.0002	0.005	0.0027	0
			0.0002	0.0002	0.005	0.0027	0
			0.0022	0.0005	0.0087	0.0028	0
				0.0005	0.013	0.0028	0.00034
				0.053	0.0006	0.08	0.0028
				0.076	0.0007	0.19	0.0029
				4.9	0.0007	0.0029	0.0011
				5.3	0.0012	0.0031	0.0012
					0.0018	0.0031	0.0019
					0.0019	0.0036	0.0026
					0.002	0.0036	0.0027
					0.0024	0.0044	0.0027
					0.003	0.0046	0.0028
					0.005	0.0055	0.0028
					0.005	0.0056	0.0028
					0.006	0.022	0.0029
					0.006	0.028	0.0029
					0.006	0.12	0.0031

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Chloroform						Methylene Chloride
Depth Interval/ Soil Volume	46-50	54-59	61-67	102-106	Cold Creek Silt	Cold Creek Carb	Cold Creek Silt
Screening Level	0.00751						0.0218
Concentration Units	mg/kg						mg/kg
	0.006						0.0031
	0.006						0.0036
	0.014						0.0046
	0.015						0.0056
	0.019						0.014
	0.024						0.02
	0.025						0.02
	0.071						0.022
	0.073						0.028
	0.073						0.03
	0.12						0.03
	0.14						0.12
	0.17						0.12
	0.25						0.198
	0.26						0.24
	0.36						0.338
							0.38
n	4	17	9	43	15	27	44
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000
max	0.110	5.30	0.024	0.360	0.190	0.120	0.380
avg	0.0316	0.6098	0.0052	0.0389	0.0213	0.0086	0.0365
90th Percentile	0.0724	1.523	0.0108	0.134	0.047	0.0105	0.120
95%UCL	0.0937	1.33	0.0220	0.0596	0.152	0.0162	0.0587

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Tetrachloroethene (PCE)						Trichloroethene (TCE)
Depth Interval / Soil Volume	54-59	61-67	68-82	102-106	Cold Creek Silt	Cold Creek Carb	61-67
Screening Level	0.000859						0.022
Concentration Units	mg/kg						mg/kg
Soil Concentration Data	0.00028	0.00029	0.00027	0.00027	0.00028	0.00032	0.00026
	0.0003	0.00029	0.00028	0.00029	0.00029	0.00032	0.000287
	0.00031	0.0003	0.00028	0.0003	0.0003	0.00032	0.000302
	0.0083	0.0003	0.00029	0.00042	0.0003	0.00032	0.00037
	0.13	0.0003	0.0003	0.0014	0.0003	0.00041	0.00038
		0.0003	0.00031	0.002	0.0003	0.002	0.00038
		0.00031	0.0024	0.0036	0.0003	0.0021	0.00039
		0.00031		0.012	0.00031	0.003	0.00039
		0.00038			0.00031	0.005	0.00039
		0.0004			0.00031	0.005	0.0004
		0.0031			0.00032	0.0054	0.00046
		0.0052			0.00032	0.006	0.00052
		0.037			0.00032	0.006	0.0013
		0.073			0.00032	0.077	0.04
		0.22			0.00032	0.19	0.047
		12			0.00032		0.11
		17			0.00034		0.17
					0.0004		
					0.000402		
					0.00063		
					0.00066		
					0.00092		
					0.00094		
					0.0012		
					0.0012		
					0.0013		
					0.0014		

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Tetrachloroethene (PCE)						Trichloroethene (TCE)
Depth Interval / Soil Volume	54-59	61-67	68-82	102-106	Cold Creek Silt	Cold Creek Carb	61-67
Screening Level	0.000859						0.022
Concentration Units	mg/kg						mg/kg
	0.0016 0.0019 0.0026 0.005 0.005 0.006 0.006 0.006 0.006 0.006 0.006 0.012 0.015 0.032 0.069 0.12 0.13						
n	5	17	7	8	44	15	17
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000
max	0.13	17	0.0024	0.012	0.130	0.190	0.170
avg	0.0278	1.7260	0.0006	0.0025	0.0101	0.0202	0.0219
90th Percentile	0.0692	3.75	0.0009	0.0053	0.0138	0.0415	0.0659
95%UCL	0.0824	3.80	0.0012	0.0074	0.0171	0.0433	0.042

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs		Technetium-99			Hexavalent Chromium			Nitrogen (nitrate+nitrite)						
Depth Interval/ Soil Volume	46-50	54-59	61-67	Cold Creek Carb	46-50	61-67	68-82	86-92	93-102	102-106	Cold Creek Silt	Cold Creek Carb	177-186	
Screening Level	3.60			0.192	9.03									
Concentration Units	pCi/g						mg/kg						mg/kg	
Soil Concentration Data	14.3 18	71.1 272	15.8 0.22	0.15 1.47	28.06 1.69	15.60 86.64	14.68 86.64	1670 1290	58.7 187	129 1403	205 126	14.3 35.5	19.8 21.2	
						23.46 9.60	10.80 384					22.1 17.2	22.5 17.2	
											103 79.0	0.181 1.35	1261 33.3	
											1261 515	515 361		
n	2	1	2	3	4	4	1	4	1	3	9	10	6	
min	14.3	71.1	15.8	0.150	1.47	1.69	14.7	384	58.7	129	0.000	0.181	12.194	
max	18.0	71.1	272	0.230	28.1	86.6	14.7	1670	58.7	236	1403	515	22.5	
avg	16.2	71.1	144	0.2000	15.6	28.7	14.7	1221	58.7	184	370	103	19.2	
90th Percentile	17.6	71.1	246	0.228	26.3	58.2	14.7	1618	58.7	226	1275	361	22.3	
95% UCL	-	-	-	-	-	74.7	-	-	-	-	672	208	22.4	

Notes: Values reported only where calculable (n >3), and not greater than the maximum value.

Values in red denote values less than detection or less than the screening level, but used in the calculation of summary statistics. Summary statistics shaded in gray denote values less than the COPC screening level.

Table E4-6. 216-A-8 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-A-8 COPCs	Carbon-14		Tc-99	Cr(VI)		N (Nitrate+Nitrite)
Depth Interval/Soil Volume (m [ft])	6.5 (21.5)	9.1 (30)	7.6 (25)	7.6 (25)	9.1 (30)	6.5 (21.5)
Screening Level	8		3.6	0.192		9.03
Concentration Units	pCi/g		pCi/g	mg/kg		mg/kg
Soil Concentration Data	81.4 0.0040	89.7	79.6	0.278 0.25	0.27 0.25	53.3 0.0609
n	1	2	1	1	2	2
avg	81.4	44.9	79.6	0.278	0.260	26.7
max	81.4	89.7	79.6	0.278	0.270	53.3
90th Percentile	-	80.7	-	-	0.268	48.0
Notes: Values in red denote values less than detection or less than the screening level. The maximum values were used as the point source term for the 216-A-8 modeling.						

E4.4.1 Uncertainty Factors and Assumptions Associated with the Estimation of Contaminated Soil Volumes

The primary uncertainty associated with the contaminated soil volumes used in the fate and transport modeling is the estimation of the lateral dimension (L) of the 1 m (3.3-ft) wide reference volume modeled as defined in Equation E4-1. The height dimension of the contaminated soil volumes (depth intervals) are reasonably well constrained by the geologic and stratigraphic relationships described in Section E4.2.1 to E4.2.4, and summarized in Table E4-1. However, the length of the contaminated soil volume parallel to the direction of groundwater flow is the largest dimension in the calculation of the soil volume, and is typically the factor with the greatest uncertainty in the volume calculation. The information necessary to reduce this uncertainty involves the extent of lateral coverage of subsurface boreholes in the vicinity of waste sites which is generally minimal (e.g., based on one to two borehole locations), and unavailable. Thus, estimations of the lateral extent of contaminated soil volumes (plumes) are generally conservatively bounding, based on assumptions or analogies to contaminant behavior conceptual models at other comparable waste sites where more data and information are available.

The spatial extent of the contaminant plumes in the vadose zone beneath the 200-PW-1/3 waste sites can be constrained to a greater degree than most other locations at the Hanford Site owing to the abundance of subsurface boreholes present at representative waste sites (39 boreholes at 216-Z-9 and 7 near the 216-Z-1A and 216-Z-18 area). The extensive evaluation of the data and information on the weight of evidence for the lateral extent of contamination in Section E4.3 presents the technical basis for the values used to define this parameter summarized in Section E4.4. Although the inherent uncertainty associated with the length and volume of the contaminated soil volumes (and calculated source term mass) is significantly reduced because of this information and evaluation, some conservative assumptions continued to be made in the estimation of the lateral dimension. As described in Section E4.4, multiples

or fractions of the waste site footprint dimensions were used to define the contaminant source term length in the modeling. Some of the possible conservatisms associated with the source term length parameter assignments include the use of the following:

- Lateral dimensions of 1× the dimension of the waste site footprint for the contaminated soil volumes for VOA COPCs
- Lateral dimensions of the nitrogen contaminant plume (2× the dimension of the waste site footprint parallel to groundwater flow) for Tc-99
- Maximum length dimensions of the COPC contaminant plumes to describe the entire contaminated soil volume in the vadose zone

The reason for the potential conservatism in the first assumption is that the data that serve as the basis for defining the lateral dimensions of the VOA contaminant plumes at the 216-Z-1A and 216-Z-18 wastes site are from 1992 to 1993, and those at the 216-Z-9 Crib are from 2001 to 2006. This is significant because the VOA concentrations are shown to have decreased linearly by as much as three orders of magnitude since the operation of the SVE began in 1992 to 1993. In addition, the VOA concentrations most certainly have continued to decrease since from 2001 to 2006 with 5 to 10 years of continued operation of the SVE (see Figures E4-11 and E4-24). These factors serve to quantify the magnitude and direction of this potential source of uncertainty.

The use of the maximum overall dimension of the contaminant plume to describe the entire contaminated soil volume in the vadose zone is conservative for contaminant plumes where the lateral dimension of the plume varies with depth, as appears to be the case for the plumes that have been defined to date (see Figures E4-18 and E4-20). Estimation of contaminated soil volumes based on a fixed length value corresponding to the maximum dimension of the plume, therefore, tends to yield conservatively inflated estimates of the volume. The magnitude of this conservatism is effectively the difference between a rectangular-shaped volume, and that of irregular ellipsoid-shaped volumes. The magnitude of the difference between rectangular-shaped volumes and spherical-shaped volumes, for example, where the rectangle length equals the spherical diameter is a factor of about 2× (1.91). The volume of ellipsoids are even less than spherical volumes.

The potential conservatism associated with the third assumption is based on the observed differences in the vertical distribution of nitrogen (nitrate) and Tc-99 concentrations beneath the 216-Z-9 Crib. The maximum lateral dimensions of the nitrogen plume in the vadose zone beneath the 216-Z-9 Crib is shown to be about 2× the dimensions of the waste site footprint in Section E4.3. The lateral dimension of the contaminated soil volume for Tc-99 at the 216-Z-9 Crib was assumed to be the same because both Nitrogen and Tc-99 are non-VOA COPC that are regarded as mobile COPCs ($K_d=0$), and unaffected by SVE operations. The volume of the nitrogen plume is based on the maximum lateral dimension of the plume that occurs in the vicinity of the Cold Creek unit, where the lateral plume dimensions tend to be the largest (see Figure E4-20); however, the contaminated soil volume for Tc-99 appears to reside primarily within the upper part of the Hanford formation, where the extent of lateral spreading is significantly less, based on the results of the PNNL studies (PNNL-14895; PNNL-15914; and PNNL-16198). Thus, the lateral dimensions and the contaminated soil volumes for the Tc-99 plume may be less than those of nitrogen, which would yield model results biased conservatively high for Tc-99.

E4.4.2 Uncertainty Factors and Assumptions Associated with the Estimation of COPC Concentrations

Estimation of representative values for the concentration of contaminated soil volumes is one of the greatest sources of uncertainty in fate and transport modeling. It is generally not known how

representative the data from limited characterization (often from one to two boreholes) are of the concentrations in the actual or modeled plume volume. However, there are generally few alternatives to the use of limited data to define source term concentrations, acknowledging the inherently large uncertainties concerning the representativeness of the data, and invoking assumptions regarding the conservative biases associated with such data where it is known or presumed to preferentially sample the more contaminated parts of vadose zone plumes. The atypical number and density of subsurface borehole samples from the 200-PW-1/3 waste sites evaluated here provide an opportunity for the other methods and factors to be also be considered in the estimation of representative concentrations of contaminated soil volumes. The following is a discussion of the basis and objectives for estimating soil volume concentrations, and of some methods and factors that can potentially improve the accuracy and reduce the uncertainty of the estimated concentrations for the modeled contaminated soil volumes.

The COPC concentration values assigned to the contaminated soil volumes are intended to represent the integrated range of concentrations within the volume most appropriate for defining representative source term masses in the modeling; therefore, entire soil volumes are treated as uniformly contaminated source terms. This is a reasonable assumption for the estimation of the source term mass when the soil concentration is indeed representative of the actual range and extent of contamination; i.e., actual average concentrations. However, the COPC concentration and associated mass estimates can be significantly biased when the data are not representative of the integrated (true) average. Common examples are when there are very few data, and/or when data are biased toward higher concentrations in the most contaminated parts of a contaminated soil volume, as is often the case with limited characterization. Examples of uncertainties associated with sparse data in the 200-PW-1/3/6 modeling include the Tc-99 data for the 216-Z-9 Crib (Table E4-5) and for the 216-A-8 Crib (Table E4-6) where there are only 1 to 3 data points for most of the depth intervals of interest.

Biases and uncertainties in COPC concentration and associated mass estimates occur when the concentration gradients and their spatial relationships are not appropriately weighted in the calculation of the overall average for the contaminated soil volume. Figure E4-29 is a schematic example of a contaminated soil volume for a generic COPC with concentration gradients depicted by the coloring within the plume, and by the four hypothetical soil concentration measurements at the designated locations within a lateral slice through the contaminated soil volume intended to represent borehole-type samples. The concentration gradients for the plume are shown in the profile below the conceptual plume. Figure E4-29 shows five scenarios for the calculation of soil concentrations from the four concentration values in the conceptual contaminated soil volume. Examples of five scenarios for the calculation of simple average concentrations for various combinations of the four data points are shown in the accompanying table together with a weighted overall average concentration value based on the dimensions and concentration gradients of the plume segments are also shown in Figure 6 (scenarios A-B, B-C, and C-D). The ratios of the dimension-based weighted (true) average concentration to simple averages of data point combinations calculated from spatially biased data range from 1.3 to 3.6 in this example, which correspond to the magnitude by which the biased measurements differ from the true average concentration of a lateral slice through the center of the plume. These values are also the approximate magnitude of overestimation of the source term mass and associated groundwater concentrations.

The magnitude of the difference (bias) between the estimated and actual “average” concentration would also increase where the concentration gradients are steeper. For example, it is indicated from cursory comparison of the average CT soil concentrations calculated for the contaminated soil volumes beneath the 216-Z-9 Crib (Section E4.6) to average concentration estimates through the 3-D contaminant plumes (Figures E4-18 to E4-21) that the use of the simple average of the data may overestimate the integrated average concentration value by as much as two orders of magnitude for some contaminated depth

intervals. Similarly, it is also indicated that the integrated average concentration values for nitrogen (in nitrate+nitrite) based on the simple average of the data may be overestimated by factors of 2 to 20 for some contaminated depth intervals.

In such cases, there are two main components of sampling bias and associated sources of uncertainty that can potentially be compounded:

- The bias associated with preferential sampling of the more contaminated portions of the contaminant plume (unrepresentative spatial distribution of the sample population laterally and vertically within the plume)
- Sampling bias associated with the sampling and measurement frequency resulting in unrepresentative frequency of measurements, which can affect the value of summary statistics for the data

Thus, the use of simple averages of such soil data tend to result in COPC concentrations that are conservatively biased toward the higher, or highest part of the population of concentrations within the contaminated soil volume. This leads to overestimation of source term masses and groundwater impacts. Conversely, sampling data that are biased by under-representing the most contaminated parts of a plume would tend to underestimate source term masses and groundwater impacts. The most probable sampling bias at most Hanford waste sites is likely toward conservatively high concentrations because the objective of most sampling efforts is to determine the levels of contamination in the most highly contaminated parts of the vadose zone.

Such biases are most likely to occur when the actual concentration gradients within a contaminant plume volume are not well represented by the sampling for the following reasons:

- There are insufficient data to represent the plume concentration gradients.
- The apparent distribution of concentrations gradients in the evaluated volume is not appropriately weighted (i.e., skewed from actual plume dimension relationships).

Additional biases can occur when the lateral extent of soil volumes used in the modeling (for a given thickness) are larger or smaller than the actual lateral dimensions of the contaminated soil volume. The mass of contamination within a contaminated soil volume varies linearly with changes in length and volume size for any given (average) concentration value. This type of bias results in overestimation of the mass and associated groundwater impacts when the contaminated soil volume is overestimated and underestimation of the mass when the volume is underestimated. Chapter E3.0 further discusses these uncertainties and potential biases. The model results are interpreted in the context of the risk analysis and possible follow-on efforts to mitigate uncertainties, which appear to dominate potential risks associated with the COPCs that have the largest uncertainties.

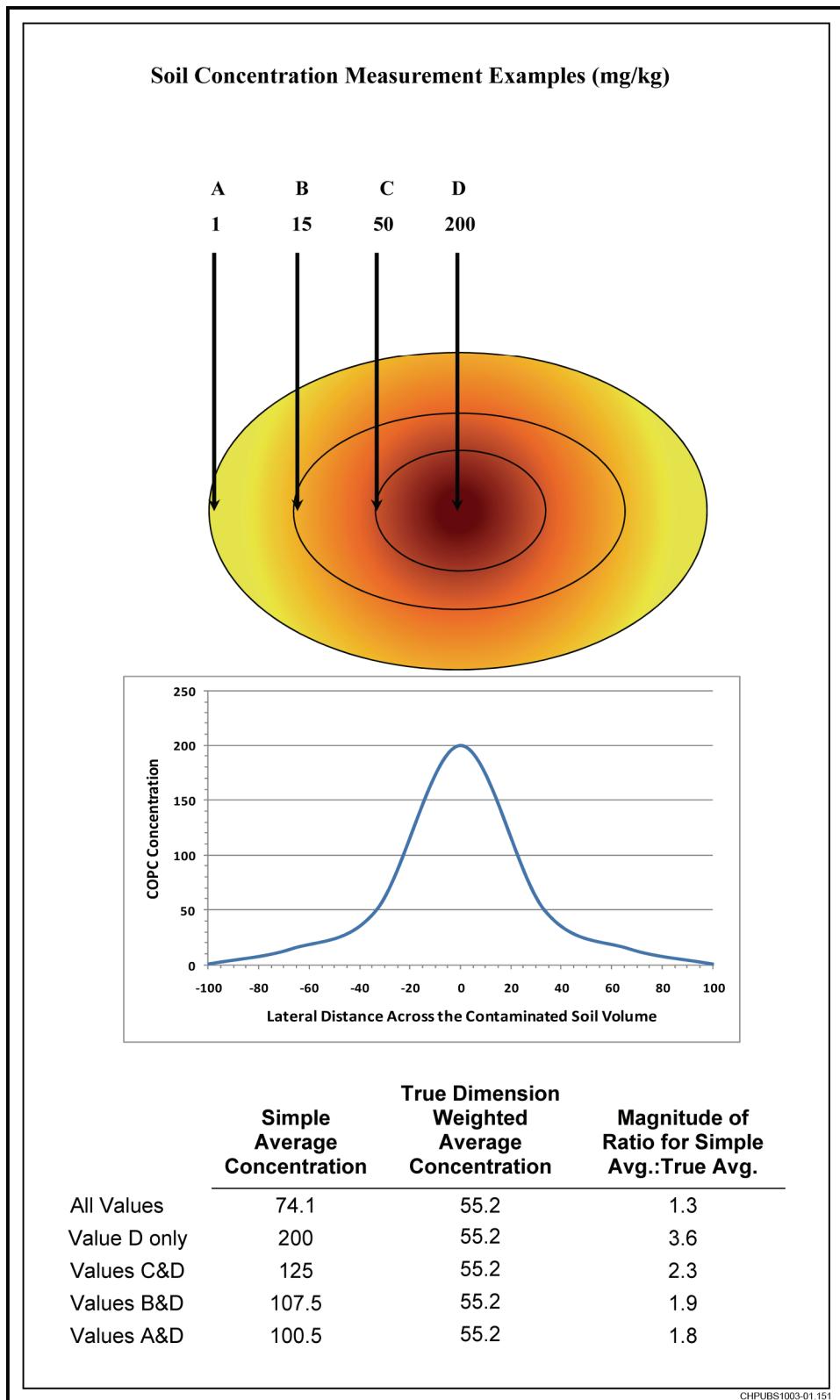


Figure E4-29. Schematic Illustration of the Direction and Magnitude of Biases in the Calculation of Average Concentrations of Contaminated Soil Volumes

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E5.0 Model Results

The purpose of the fate and transport modeling is to evaluate the impacts to groundwater associated with contamination in the vadose zone at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs that are located in the 200-PW-1/3/6 OUs. The modeling includes both an additional screening phase and an evaluation of the groundwater concentrations and contaminant arrival times during the 1,000-year evaluation period. Options provided in EPA/540/F-95/041, *Soil Screening Guidance: Fact Sheet*, for screening include the use of site-specific results developed from detailed modeling. In the screening phase of the fate and transport modeling, contaminants are screened from further evaluation if the model results indicate that the contaminants do not reach the water table within 1,000 years. The results of contaminant screening in Section E3.0 provided the list of contaminants that could not be initially screened out as COPCs with respect to the protection of groundwater pathway.

Contaminants that are not screened out from consideration during this phase are included in the evaluation of the impacts to groundwater. Model predicted groundwater concentrations are then compared to the MCLs for the specific contaminants evaluated. Based on the federal guidelines for the selection and use of model types and codes specifically for risk characterization purposes, it is indicated that 2-D fate and transport modeling is an appropriate model type for the Central Plateau of the Hanford Site as a subsequent screening and/or risk characterization method for evaluation groundwater protection (EPA/540/F-95/041 and DOE/RL-2007-34, *Regulatory Criteria for the Selection of Vadose Zone Modeling in Support of the 200-UW-1 Operable Unit*).

The modeling to evaluate the possible impacts to groundwater resulting from vadose zone contamination at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs included the use of numerical two-dimensional flow, fate, and transport models. The basis and rationale for using this type of model for this type of evaluation, and the overall vadose zone model and code selection process, is described in DOE/RL-2007-34. The Subsurface Transport Over Multiple Phases (STOMP) code was used to perform the calculations based on its ability to incorporate adequately the vadose zone features, events, and processes (FEPs) relevant at the Hanford Site and to satisfy the other code criteria and attributes identified in DOE/RL-2007-34.

A sensitivity analysis was performed in which selected model parameters were varied in order to determine model results as a function of changes in parameter values. The key input parameters varied in the sensitivity analysis include the post-remediation recharge rate and the initial contaminant distribution in the vadose zone. For the purpose of this evaluation, statistical estimates of the contaminant concentration developed based on the sampling data were used for the inventory approximation. The reference case evaluation were based on the estimated long term recharge rate representing the most probable surface end state after the minimum remediation (reclamation of the shrub-steppe surface and vegetation) has occurred.

E5.1 Contaminants of Potential Concern

The COPCs addressed in this evaluation were identified by the screening process, as listed in Table E5-1. The contaminant screening process included a criterion developed based on the maximum contaminant K_d value that would reach the groundwater within 1,000 years from the maximum depth of contamination identified at the waste sites. For the 216-A-8 Crib screening analysis, contaminants that passed the initial screening analyses steps were assumed to exist in the model approximately 15.5 m (52 ft) bgs. Below this depth, none of the contaminants with K_d value greater than zero was detected at levels above background concentration values. For the 216-Z-1A, 216-Z-18, and 216-Z-9 Cribs screening analyses, contaminants that passed the initial screening analyses steps were assumed to exist in the model in the Cold Creek

carbonate unit because below this geologic unit none of the contaminants with K_d values greater than zero were detected at levels above background concentration values, with one exception.¹¹ The results of the models essentially provided a K_d screening step for the contaminants of potential concern. Based on the screening model results, contaminants with K_d values greater than the particular value calculated in the model do not arrive in groundwater within 1,000 years; therefore, these contaminants were screened from further evaluation.

Table E5-1. COPCs Identified in the Screening Analysis to Include in the Fate and Transport Modeling for the Protection of Groundwater at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs

216-Z-1A	216-Z-18	216-Z-9	216-A-8
1, 1-Dichloroethane	Benzene	1,1,2,2-Tetrachloroethane	Hexavalent chromium
Carbon tetrachloride	Carbon tetrachloride	1,1,2-Trichloroethane	Nitrogen in nitrate and nitrite
Chloroform	Chloroform	1-Butanol	Carbon-14
Methylene chloride	Ethylbenzene	Bromodichloromethane	Technetium-99
Tetrachloroethene	Methylene chloride	Bromoform	
Trichloroethylene	Tetrachloroethene	Carbon tetrachloride	
Nitrogen in nitrate and nitrite	Nitrogen in nitrate and nitrite	Chloroform	
		Methylene chloride	
		Tetrachloroethene	
		Trichloroethylene	
		Technetium-99	
		Hexavalent chromium	
		Nitrogen in nitrate and nitrite	

The contaminant screening and evaluation of the groundwater impacts modeling at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs consisted of three stages. The first stage established steady state hydraulic conditions within the model domain using boundary conditions consistent with conditions assumed to exist prior to the construction of the Hanford Site in the early 1940s. The second stage represented transient hydraulic conditions during the period from 1944 to 2010 (from the beginning time of Hanford Site operations to the present). During this second stage, the recharge boundary condition applied to the crib dimensions was increased to reflect the altered surface conditions associated with the construction of the cribs, and water source terms were included to simulate the discharge histories of the cribs. The third stage started in 2010 and represented future hydraulic and contaminant transport for future surface conditions. The estimated vadose zone contaminant profile was input to the model as an initial condition at the beginning of this third stage, and the contaminant transport through the vadose zone and resulting groundwater impacts were calculated. Closure of the 216-A-8 Crib is assumed to occur no sooner than 2016, and closure of the 216-Z-1A, 216-Z-18, and 216-Z-9 cribs is assumed to occur no sooner than 2020. Boundary conditions representing recharge for the changed surface conditions associated with the possible post-remedy surface conditions commenced with the assumed dates of closure.

¹¹ A single value of radium-228 measured in sample collected from one of the 216-Z-9 characterization boreholes at a depth of 59.4 m (195 ft) bgs exceeded the screening criteria presented in Section E3.

E5.2 Methodology and Approach for Fate and Transport Modeling

DOE/RL-2007-34 contains the description of the generalized models, conditions, and parameters applicable to the Hanford Site vadose zone, which were refined and augmented for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs evaluation. In addition, several vadose zone modeling evaluations of the 216-Z-1A, 216-Z-18, and 216-Z-9 Cribs have been conducted as part of the investigation of the distribution and mobility of discharged CT (e.g., PNNL-14895, PNNL-15914, and PNNL-16198). These evaluations provide the basis for most of the conceptual model components and parameters for the 216-Z-1A, 216-Z-18, and 216-Z-9 Cribs models.

E5.3 Conceptual Model Components and Parameter Selection

The site-specific conceptual model components for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs evaluation are:

- Model domain and boundary conditions
- Geologic setting
- Source term
- Groundwater domain and characteristics
- Vadose zone hydrogeology and fluid transport
- Recharge
- Geochemistry

Although the model domain and boundary conditions are not generally regarded as conceptual model elements, they are included in the list above to emphasize the fundamental nature of boundary conditions in the modeling. Because of the proximity of the 216-Z-18 Crib to the 216-Z-1A Crib, and the similarity of the conceptual model components, the model developed for the 216-Z-1A Crib was also used to evaluate the COPCs identified for the 216-Z-18 Crib. Thus, the 216-Z-18 Crib model is identical to the 216-Z-1A Crib model, with the exception of the contaminant source terms.

Pursuant to CERCLA and pertinent applicant or relevant and appropriate requirement (ARAR)-driven Washington State requirements for determining soil cleanup levels for the uppermost part of the vadose zone soils, the evaluation used modeling assumptions and parameter estimates appropriate for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs site-specific conditions. Table E5-2 provides a summary of key elements and parameters for the conceptual model components, which are identified in the left hand column of the table. The following subsections for the individual conceptual model components provide the basis, rationale, and references for the values. These parameters represent the values selected for use in the model from the ranges of plausible parameter values. These values may differ from parameter estimates for other Hanford Site modeling performed for different purposes or areas of the Hanford Site, or at different scales.

E5.3.1 Model Domain and Boundary Conditions

The model domain and boundary conditions establish both a framework and limiting conditions for the numerical model. The model domain for flow and transport in the vadose zone is represented numerically as a 2-D, vertical cross-section aligned in the general direction of groundwater flow. Aligning the vertical cross-sections with the general direction of groundwater flow allows concentrations to be calculated downgradient of the waste sites. The numerical model adapts the physical elements of the conceptual model to a Cartesian grid and assigns numerical values to the parameters used in algorithms to represent the physical and geochemical systems and processes.

Table E5-2. Summary of Key Elements and Parameters Associated with Site-Specific Model Components for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Model Domain and Boundary Conditions	216-Z-1A Crib, 400 m (1,312 ft) x 1 m x 88.5 m (290 ft) 216-Z-9 Crib, 440 m (1,444 ft) x 1 m x 84 m (276 ft) 216-A-8 Crib, 2610 m (6,660 ft) x 1 m x 95 m (312 ft) Prescribed flux across the top (recharge); no-flow along vertical side boundaries in the vadose zone; prescribed head at the along vertical side boundaries in the aquifer, including the capillary fringe; no-flow along the bottom of the model (aquifer)
Geologic Setting	216-Z-1A and 216-Z-9 Cribs geologic setting includes the following stratigraphic units that occur from surface to groundwater (PNNL-15914 and PNNL-16198): <ul style="list-style-type: none"> • Backfill • Hanford Upper Fine (very coarse to medium sand to slightly pebbly very coarse sand, with some silty stringers) • Hanford H1 (open framework gravel to coarse to medium sand) • Hanford H2 (interbedded sand and slightly silty/clayey sand) • Hanford Lower Gravel (unconsolidated gravel, sandy gravel, and/or silty sandy gravel) • Hanford Lower Sand (coarse to medium sand to silty fine to very fine sand, with some silt to silty-clayey sand lenses) • Cold Creek silt (cohesive, compact, massive to laminated and stratified fine-grained sand and silt) • Cold Creek carbonate (fine- to coarse-grained, calcium-carbonate cemented paleosol) • Upper Ringold (slightly muddy, slightly gravelly, coarse to medium sand) • Ringold E (semi-indurated fluvial muddy sand gravel) The 216-A-8 Crib geologic setting includes several stratigraphic units that alternate from surface to groundwater according to the following pattern (Figure E4-1(c)): <ul style="list-style-type: none"> • Crib Backfill (6 m [20 ft]) • Hanford H1 Coarse Sand (9 m [30 ft]) • Hanford H1 Gravelly Sand (2 m [7 ft]) • Hanford H1 Coarse Sand (6 m [20 ft]) • Hanford H2 Fine Sand (2 m [7 ft]) • Hanford H2 Coarse Sand (4 m [13 ft]) • Hanford H2 Silty Sand (2 m [7 ft]) • Hanford H2 Coarse Sand (5 m [16 ft]) • Plio-Pleistocene Silt (1 m [3 ft]) • Hanford H2 Coarse Sand (1 m [3 ft]) • Plio-Pleistocene Silt (2 m [7 ft]) • Hanford H2 Silty Sand (2 m [7 ft]) • Hanford H2 Coarse Sand (6 m [20 ft]) • Plio-Pleistocene Silt (1 m [3 ft]) • Hanford H2 Coarse Sand (1 m [3 ft]) • Hanford H2 Silty Sand (2 m [7 ft]) • Hanford H3 Gravelly Sand (2 m [7 ft]) • Hanford H3 Sandy Gravel (5 m [16 ft]) • Hanford H3 Gravelly Sand (3 m [10 ft]) • Hanford H3 Sandy Gravel (4 m [13 ft]) • Hanford H3 Coarse Sand (4 m [13 ft]) • Ringold Gravel – Vadose (8 m [26 ft]) • Ringold Gravel – Aquifer (15 m [49 ft])

Table E5-2. Summary of Key Elements and Parameters Associated with Site-Specific Model Components for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Source Term	<p>Contamination Length Parallel to Groundwater Flow Specified contaminant source term dimensions for re-vegetated shrub or evapotranspiration barrier surfaces:</p> <ul style="list-style-type: none"> • 216-Z-1A Crib: 108 m (354 ft) (twice the length of the crib dimension at ground surface 53.3 m [175 ft] rounded to 54 m [177 ft] [Figure 2-4]) • 216-Z-9 Crib: 55 m (180 ft) (twice the length of the crib dimension at ground surface 27.4 m [90 ft] [Figure 2-3] rounded up) • 216-A-8 Crib: 65, 130, 130 m [213, 427, 853 ft] (one-quarter, one-half, and one times the length of the crib dimension at ground surface 259 m [850 ft] rounded to nearest even number: 260 m [853 ft] [Figure 2-10 and Figure E4-1(c)]) <p>Specified contaminant source term dimensions for non re-vegetated shrub surfaces:</p> <ul style="list-style-type: none"> • 216-Z-1A Crib: 54 m [177 ft] (the length of the crib dimension at ground surface [53.3 m {175 ft}] [Figure 2-4] rounded up) • 216-Z-9 Crib: 27 m [89 ft] (the length of the crib dimension at ground surface [27.4 m {90 ft}] rounded down [Figure 2-3]) • 216-A-8 Crib: No change <p>Source-term depths (m or ft-bgs, inclusive):</p> <ul style="list-style-type: none"> • 216-Z-1A Crib, 6 to 43 m (20 to 140.5 ft) • 216-Z-9 Crib, 6 to 37 m (20 to 186 ft) • 216-A-8 Crib, 6 to 9 m (21.5 to 106.5 ft) <p>Unlimited advective release, K_d control only</p>
Groundwater Domain and Characteristics	<p>Water table elevation calendar year 2009 approximately 134.5 m (441 ft) NAVD88 at 216-Z-1A and 216-Z-9 Cribs and approximately 119 m (390 ft) NAVD88 at 216-A-8 Crib</p> <p>Groundwater thickness limited to approximately 15 m (50 ft) in the aquifer; Groundwater concentrations evaluated for upper 5 and 10 m (16 and 33 ft) of aquifer</p> <p>Average hydraulic conductivity and 4.95 m/day at 216-Z-1A and 216-Z-9 Cribs and 1,000 m/day at 216-A-8 Crib</p> <p>Hydraulic gradient approximately 0.0011 m/m at 216-Z-1A and 216-Z-9 Cribs and 0.00001 m/m at 216-A-8 Crib</p>
Vadose Zone Hydrogeology and Fluid Transport	<p>K_d-control for contaminant transport</p> <p>Hydrogeologic properties for 216-Z-1A and 216-Z-9 Cribs models adapted from PNNL-14895, PNNL-15914, and PNNL-16198. Hydrogeologic properties for 216-A-8 Crib model derived from PNNL-14702</p> <p>Hydraulic Conductivity and Dispersion Horizontal to Vertical Anisotropy 10:1</p>
Recharge	<p>Pre-Operational; undisturbed ground: 4 mm/yr</p> <p>Operational through Pre-Remediation: 63 mm/yr [12/1955 through 2010]</p> <p>Post-Remediation:</p> <ul style="list-style-type: none"> • Surface evapotranspiration barrier: 0.5 mm/yr for 500 years, 1 mm/yr long-term • Revegetated shrub on disturbed soil: 8 mm/yr for 30 years, 4 mm/yr long-term • Non-revegetated shrub (grasses only) on disturbed soil: 22 mm/yr long-term • Continuation of operational: 63 mm/yr long-term

Table E5-2. Summary of Key Elements and Parameters Associated with Site-Specific Model Components for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Geochemistry	Hexavalent Chromium K_d = 0 mL/g in all stratigraphic units Nitrogen in Nitrate and Nitrite K_d = 0 mL/g in all stratigraphic units 1,1,2,2-Tetrachloroethane K_d = 0.05 mL/g in all stratigraphic units 1,1,2-Trichloroethane K_d = 0.05 mL/g in all stratigraphic units 1, 1-Dichloroethane K_d = 0.05 mL/g in all stratigraphic units 1-Butanol K_d = 0.01 mL/g in all stratigraphic units Bromodichloromethane K_d = 0.05 mL/g in all stratigraphic units Bromoform K_d = 0.1 mL/g in all stratigraphic units Carbon Tetrachloride K_d = 0.15 mL/g in all stratigraphic units Chloroform K_d = 0.05 mL/g in all stratigraphic units Methylene Chloride K_d = 0.01 mL/g in all stratigraphic units Radium-228 K_d = 3 mL/g in all stratigraphic units Tetrachloroethene K_d = 0.25 mL/g in all stratigraphic units Trichloroethylene K_d = 0.1 mL/g in all stratigraphic units Carbon-14 K_d = 0 mL/g in all stratigraphic units Technetium-99 K_d = 0 mL/g in all stratigraphic units
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Notes:

The basis for elements and parameters selection provided in the individual model components sections.

NAVD88, *North American Vertical Datum of 1988*.

PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*.

PNNL-14895, *Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site*.

PNNL-15914, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-9 Trench at the Hanford Site: Heterogeneous Model Development and Soil Vapor Extraction Modeling*.

PNNL-16198, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and 216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*.

The 216-Z-1A and 216-Z-9 Cribs model domains were 400 m (1,312 ft) and 440 m (1,444 ft) horizontally, respectively, by 1 m (3.3 ft), by approximately 88.5 m (290 ft) and 84 m (276 ft), respectively, vertically, extending about 15 m (49 ft) below the water table. A horizontal-to-vertical node spacing of 1 m:0.5 m was used throughout each model domain. The total number of nodes equaled 70,800 and 73,920, respectively. Digitization of Figure 3.8 in PNNL-16198 and Figure 2.4 in PNNL-15914 provided the basis for the size of the 216-Z-1A and 216-Z-9 Cribs model domains, respectively. Two-dimensionally within the model grid, the 216-Z-1A Crib extended 54 m (175 ft) at the surface, tapering to 30 m (100 ft) at the base at a depth of 6 m (19 ft) (Figure E2-4). The 216-Z-9 Crib extended 27 m (90 ft) at the surface, tapering to 9 m (30 ft) at the base at a depth of 6 m (20 ft) (Figure E2-3).

The 216-A-8 Crib model domain was 2,610 m (8,560 ft) by 1 m (3.3 ft) horizontally, by 95 m (312 ft), vertically, extending about 15 m (49 ft) below the water table. Because of the size of the crib and the volume of water discharged to it, the grid for the 216-A-8 Crib required a relatively large domain to minimize boundary effects during the high volume discharge period 1955 to 1985. A horizontal-to-vertical node spacing of 3 m:1 m was used in the outer 870 m (2,854 ft) sides of the model, and a horizontal-to-vertical node spacing of 2 m:1 m was used through the center of the model domain 870 m (2,854 ft). The total

number of nodes equaled 96,425. Two-dimensionally, the 216-A-8 Crib extended 260 m (850 ft) at the surface, tapering to 129 m (423 ft) at the base at a depth of 6 m (approximately 16 to 19 ft, the crib bottom is sloped) (Figure E4-10 and drawing H-2-56157, *Crib 216-A-8 & Control Structure 216-A-508 Plan and Details*).

A specified-flux boundary condition was applied at the surface to simulate recharge. Recharge rates varied spatially and temporally along the upper boundary depending on site conditions, the location and physical dimensions of the waste site, and the time of waste site operations and surface conditions simulated. Boundary conditions at the sides of the model domain were assumed to be no flow in the vadose zone and prescribed head in the aquifer, including the capillary fringe. Section E5.5 addresses the function of these boundary condition assumptions. The bottom boundary of the unsaturated (vadose) zone is the water table. The bottom of the model (aquifer) was defined as a vertical no flow boundary condition.

PNNL-16198 provides estimates of the annual discharge volume to the 216-Z-1A Crib, shown in Table E5-3. The Effluent Volume to Soil Disposal Sites (EVSDS) module of the Hanford Virtual Library (available at: <http://vlprod.rl.gov/vlib/>) provides estimates of the annual discharge to the 216-Z-9 and 216-A-8 Cribs, as summarized in Table E5-4.

Table E5-3. Discharged Aqueous Volumes and DNAPL Volumes for the 216-Z-1A Crib

Year	Aqueous Phase Volume (L)	DNAPL Volume (L)
1949	6.00E+04	—
1950	1.00E+05	—
1951	1.00E+05	—
1952	1.00E+05	—
1953	1.00E+05	—
1954	1.00E+05	—
1955	1.00E+05	—
1956	1.00E+05	—
1957	1.00E+05	—
1958	1.00E+05	—
1959	4.00E+04	—
1960 – 4/1963	—	—
Z-1AA		
5/1964 – 12/1964	4.20E+05	2.00E+04
1965	9.20E+05	4.10E+04
1/1966 – 5/1966	5.40E+05	2.52E+04
Z-1AB		
6/1966 – 12/1966	9.60E+05	4.48E+04
1/1967 – 9/1967	9.40E+05	3.94E+04

Table E5-3. Discharged Aqueous Volumes and DNAPL Volumes for the 216-Z-1A Crib

Year	Aqueous Phase Volume (L)	DNAPL Volume (L)
Z-1AC		
10/1967 – 12/1967	2.53E+05	1.06E+04
1968	1.00E+06	4.50E+04
1/1969 – 4/1969	1.55E+05	7.00E+03
Total	6.21E+06	2.42E+05

Source: Excerpted from PNNL-16198, Table 4.3.

Table E5-4. Discharge Volumes to the 216-Z-9 and 216-A-8 Cribs

216-Z-9 Crib			216-A-8 Crib		
Year	Volume (L)	Cumulative	Year	Volume (L)	Cumulative
1955	2.60E+05	2.60E+05	1955	7.90E+07	7.90E+07
1956	4.60E+05	7.20E+05	1956	5.06E+08	5.85E+08
1957	5.40E+05	1.26E+06	1957	2.33E+08	8.18E+08
1958	7.00E+05	1.96E+06	1958	1.12E+08	9.30E+08
1959	5.60E+05	2.52E+06	1966	3.66E+06	9.34E+08
1960	6.20E+05	3.14E+06	1967	9.62E+07	1.03E+09
1961	7.70E+05	3.91E+06	1968	2.67E+07	1.06E+09
1962	1.80E+05	4.09E+06	1969	2.41E+07	1.08E+09
			1970	1.15E+07	1.09E+09
			1971	1.83E+07	1.11E+09
			1972	1.12E+07	1.12E+09
			1973	6.65E+06	1.13E+09
			1974	1.40E+07	1.14E+09
			1975	6.49E+06	1.15E+09
			1976	4.60E+05	1.15E+09
			1978	6.06E+02	1.15E+09
			1983	1.33E+05	1.15E+09
			1984	1.08E+06	1.15E+09
			1985	2.31E+05	1.15E+09

Notes: Red shading denotes maximum annual volume and blue shading denotes minimum annual volume.

Source: Hanford Virtual Library (<http://vlprod.rl.gov/vlib>)

E5.3.2 Geologic Setting

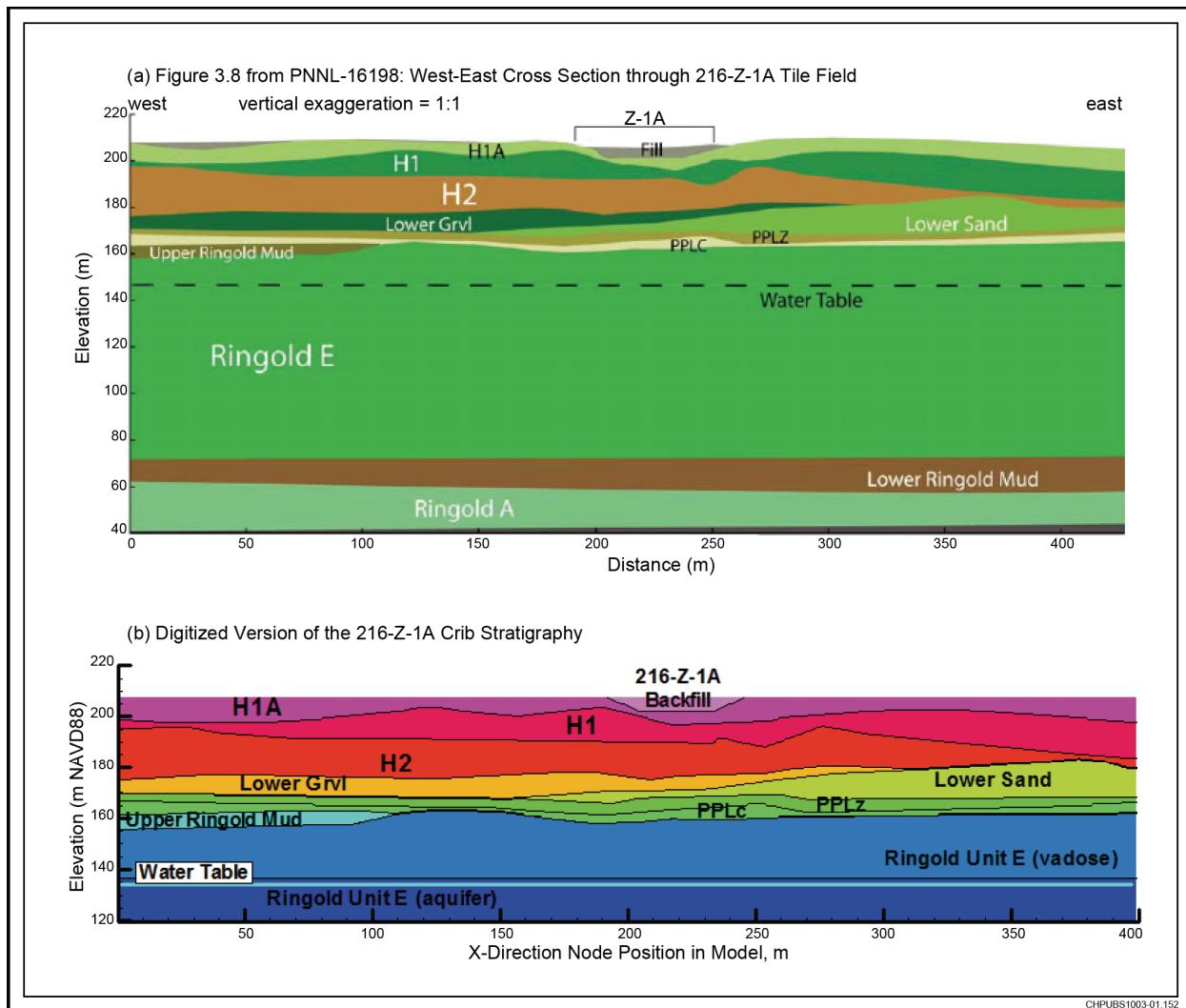
The stratigraphy shown in Figure 3.8 in PNNL-16198 and Figure 2.4 in PNNL-15914 provided the basis for the 216-Z-1A and 216-Z-9 Cribs model domains, respectively. Comparisons of those figures to the digitized versions of the figures used in this evaluation are shown in Figures E5-1 and E5-2, respectively. The water table elevation beneath the 216-Z-1A and 216-Z-9 Cribs was estimated to be approximately 134.5 m (743 ft) NAVD88 (water level measured 134.4 m [441 ft] NAVD88 in March 2008 and 135 m [443 ft] in March 2009 NAVD88 in wells 299-W15-38 and 299-W15-42, respectively, Hanford Virtual Library, available at: <http://vlprod.rl.gov/vlib/>). Therefore, the total thickness of the vadose zone in the models is 73.5 m (241 ft) and 69 m (226 ft) bgs, respectively. Where crib backfill exists, it is contained within the depth of the Hanford H1A sand unit. The Ringold Gravel Aquifer includes 2 m (6 ft) of Ringold Gravel Vadose as capillary fringe. The approximate unit thicknesses of the stratigraphy included in the models are listed below.

Waste Site Models 216-Z-1A and 216-Z-18 Cribs

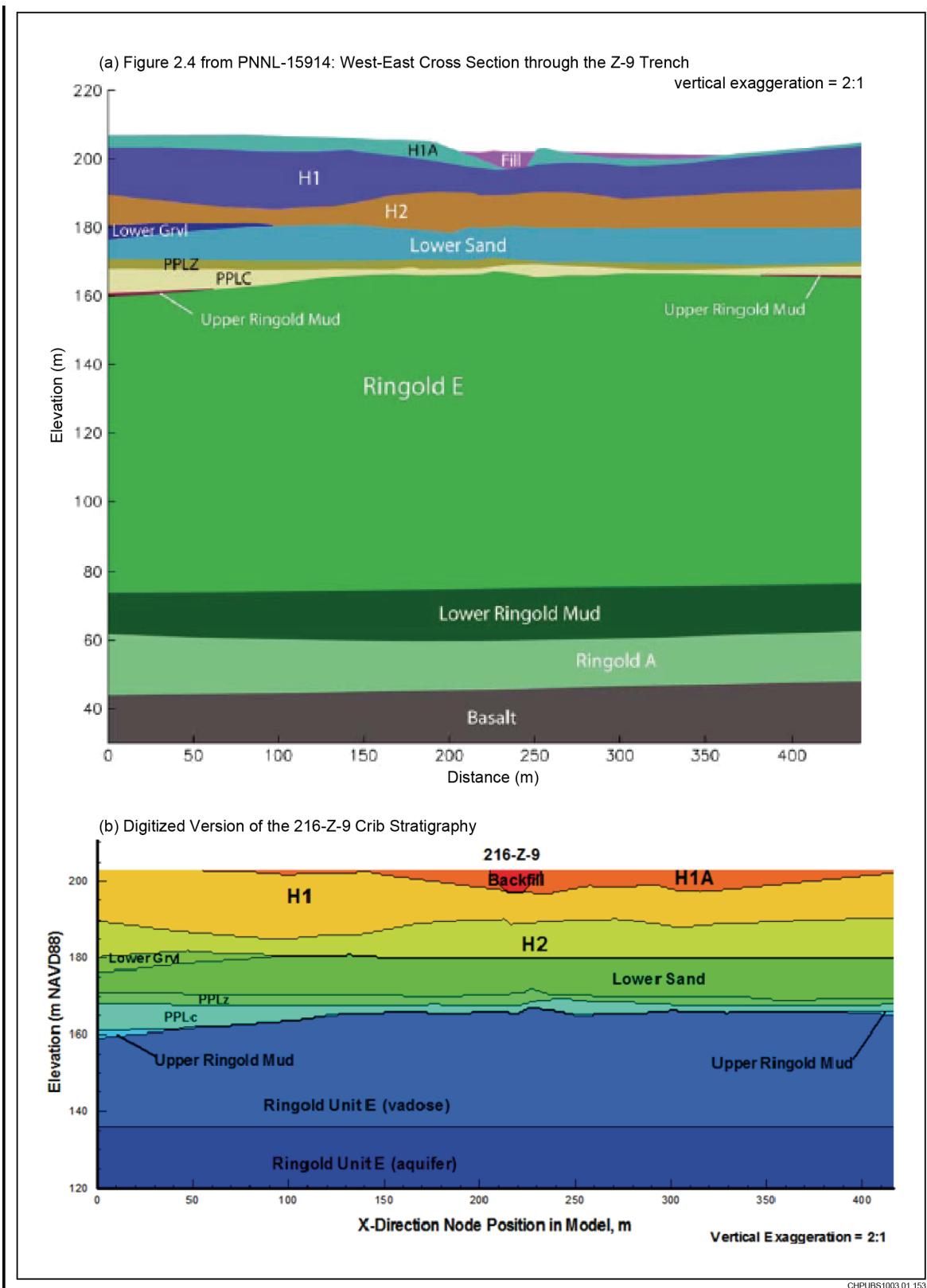
Backfill	6 m (20 ft)
Hanford Upper Fine (H1A)	4.2 m (14 ft)
Hanford H1	8.0 m (26 ft)
Hanford H2	13.7 m (45 ft)
Hanford Lower Gravel	5.3 m (17 ft)
Hanford Lower Sand	2.8 m (9 ft)
Cold Creek Silt	4.5 m (15 ft)
Cold Creek Carbonate	4.2 m (14 ft)
Upper Ringold	Not present beneath bottom of crib
Ringold Gravel – Vadose	22.9 m (75 ft)
Ringold Gravel – Aquifer	17 m (56 ft)

Waste Site Models 216-Z-9 Crib

Backfill	6 m (20 ft)
Hanford Upper Fine (H1A)	Not present beneath bottom of crib
Hanford H1	8.0 m (26 ft)
Hanford H2	9.0 m (30 ft)
Hanford Lower Gravel	Not present beneath bottom of crib
Hanford Lower Sand	9.1 m (30 ft)
Cold Creek Silt	3.3 m (11 ft)
Cold Creek Carbonate	1.9 m (6 ft)
Upper Ringold	Not present beneath bottom of crib
Ringold Gravel – Vadose	29.7 m (97 ft)
Ringold Gravel – Aquifer	17 m (56 ft)



**Figure E5-1. (a) Comparison of the 216-Z-1A Crib Stratigraphy Figure Presented in PNNL-16198 to the
(b) Digitized Version of the Figure Used in this Evaluation (also applicable to 216-Z-18)**



**Figure E5-2. (a) Comparison of the 216-Z-9 Crib Stratigraphy Figure Presented in PNNL-15914 to the
(b) Digitized Version of the Figure Used in this Evaluation**

The stratigraphy near the 216-A-8 Crib is based on the borehole log from borehole C4545, which was drilled through the bottom of the crib. The upper portion of borehole C4545 encountered 0.5 m (1.5 ft) of crushed rock, used to construct the drill pad, overlying the crib construction backfill consisting of 1.4 m (4.5 ft) of gravelly sand, 2.1 m (7.0 ft) of sand, and 1.8 m (6.0 ft) of very coarse gravel. The interval beneath the crib construction backfill, extending from 5.8 to 54.3 m (19.0 to 178.0 ft) bgs, consists of well-stratified, very fine to coarse-grained sands belonging to the sand dominated sequence of the Hanford formation (H2). Several intervals within Hanford formation H2 contain finer grained silty sands. The interval from 54.3 to 74.8 m (178.0 to 245.5 ft) bgs consists of the gravel-dominated sequence of the Hanford formation (H3). These gravels consist of poorly sorted, angular to sub rounded heterolithic cobbles (basalts and other dominantly igneous lithologies). The interval from 74.8 to 80.6 m (245.5 to 264.5 ft) bgs (total depth) consists of sandy gravels of the Ringold Formation unit 9. These sediments consist of clast to matrix-supported pebble (2 to 64 mm [0.008 to 2.5 in.]) to cobble (64 to 256 mm [2.5 to 10 in.]) heterolithic gravels with a fine to coarse-grained sandy matrix. Lenticular sand and silt interbeds also are characteristic of the Ringold Formation Unit 9. The stratigraphy generally is consistent with the borehole logs from other wells adjacent to the crib. Groundwater beneath the 216-A-8 Crib was approximately 80 m (261.7 ft) bgs at borehole C4545, thus the total thickness of the vadose zone is 80 m (315 ft). Where crib backfill exists, it is contained within the depth of the Hanford H1 coarse sand. The stratigraphy included in the model was divided into the hydrostratigraphic units with approximate unit thicknesses as illustrated in Table E5-5.

The Ringold Gravel aquifer unit adds approximately 2 m (6.6 ft) of capillary fringe from the Ringold Gravel vadose unit, which is directly above the water table. This model is proposed as an acceptable representation of the geologic setting for the 216-A-8 Crib.

E5.3.3 Contaminant Source Term

For the screening analyses, the contaminant source terms were placed at the maximum depths at which contaminants with K_d values greater than zero were detected at levels above background concentration values. With respect to the 216-Z-1A, 216-Z-18, and 216-Z-9 Cribs screening analyses, none of the contaminants with K_d values greater than zero, with the exception of a single Rd-226 sample result, were detected at levels above background concentration values below the Cold Creek carbonate unit. A range of contaminant K_d values (specifically, 0.26 mL/g, 0.6 mL/g, 1.2 mL/g, and 1.9 mL/g, 2.85 mL/g, 2.90 mL/g, 3.0 mL/g, and 3.25 mL/g) was evaluated to determine the minimum contaminant K_d value such that contaminants with this value and located as deep as the Cold Creek carbonate unit (see Figure E2-4) would not arrive in groundwater within 1,000 years. These contaminants can be screened from further evaluation. With respect to the 216-A-8 Crib screening analysis, none of the contaminants with K_d value greater than zero was detected above background concentration values below approximately 15.5 m (52 ft) bgs (Figure E2-5). A range of contaminant K_d values (specifically, 0.1 mL/g, 0.8 mL/g, and 1.0 mL/g) was evaluated to determine the minimum K_d value such that contaminants with this K_d value and located as deep as 15.5 m (52 ft) bgs would not arrive in groundwater within 1,000 years. Contaminants with K_d values greater than the minimum can be screened from further evaluation. Contaminants with K_d values less than the minimum value and not screened for the other reasons described in Sections E2 and E3 were then evaluated in the contaminant fate and transport model to determine their impacts to groundwater.

In the contaminant fate and transport analyses, three types of contaminant source terms are considered to be representative of the vertical profile of the contaminant distribution: point sources, contamination contained in geologically similar material within a geologic unit, and contamination contained throughout a geologic unit. The different contaminant source types are identified and described in Section E4. The different contaminant source types are used to identify and approximate depth-based intervals in the

Table E5-5. Approximate Thicknesses of the Geologic Layers in the 216-A-8 Crib Model

Stratigraphic Unit	Approximate Thicknesses in 216-A-8 Crib Model	
	Geologic Cross-Section	Model Approximation
Crib Backfill ^a	5.8 m (19 ft)	6 m (20 ft)
Hanford H1 Coarse Sand	14.6 m (29 ft)	15 m (30 ft)
Hanford H1 Gravelly Sand	2.1 m (7 ft)	2 m (7 ft)
Hanford H1 Coarse Sand	6.4 m (21 ft)	6 m (20 ft)
Hanford H2 Fine Sand	2.4 m (8 ft)	2 m (7 ft)
Hanford H2 Coarse Sand	4.6 m (15 ft)	4 m (13 ft)
Hanford H2 Silty Sand	1.5 m (5 ft)	2 m (7 ft)
Hanford H2 Coarse Sand	4.6 m (15 ft)	5 m (16 ft)
Plio-Pleistocene Silt	1.2 m (4 ft)	1 m (3 ft)
Hanford H2 Coarse Sand	1.2 m (4 ft)	1 m (3 ft)
Plio-Pleistocene Silt	1.8 m (6 ft)	2 m (7 ft)
Hanford H2 Silty Sand	1.5 m (5 ft)	2 m (7 ft)
Hanford H2 Coarse Sand	6.2 m (20 ft)	6 m (20 ft)
Plio-Pleistocene Silt	1.1 m (4 ft)	1 m (3 ft)
Hanford H2 Coarse Sand	1.2 m (4 ft)	1 m (3 ft)
Hanford H2 Silty Sand	2.1 m (7 ft)	2 m (7 ft)
Hanford H3 Gravelly Sand	1.5 m (5 ft)	2 m (7 ft)
Hanford H3 Sandy Gravel	4.9 m (16 ft)	5 m (16 ft)
Hanford H3 Gravelly Sand	3.4 m (11 ft)	3 m (10 ft)
Hanford H3 Sandy Gravel	3.8 m (12 ft)	4 m (13 ft)
Hanford H3 Gravelly Sand	4.4 m (14 ft)	4 m (13 ft)
Hanford H3 Coarse Sand	1.7 m (6 ft)	2 m (7 ft)
Ringold Gravel – Vadose ^b	7.8 m (26 ft)	6 m (20 ft)
Ringold Gravel – Aquifer ^b	15.0 m (49 ft)	17 m (56 ft)

a. Crib Backfill is contained within the Hanford H1 coarse sand.

b. Ringold Gravel – Aquifer includes 2 m (6 ft) of Ringold Gravel – Vadose as capillary fringe.

vadose zone that are common to the various locations where contaminant data have been collected. As described and indicated in Section E4, the vertical distribution of contamination appears to follow consistent patterns from borehole to borehole that conform to the geologic description, i.e., finer textured materials typically contain higher levels of contamination than coarser textured materials, where contaminants are often not detected or not detected above background levels. Thus, the depth intervals allow the pooling of contaminant data that describe the contamination in the same geologic interval identified in multiple locations, i.e. a fine textured lens occurring in different characterization boreholes. Contaminant sources are considered to be point sources where the sampling results indicated that the contaminant was isolated depth-wise because it was detected only intermittently vertically and not distributed throughout a lithologic layer. Point sources were assumed to have a thickness of 1 m (3.3 ft).

The sources contained in geologically similar material within a geologic unit were all assumed to be rectangular shaped with a thickness approximately equal to the thickness of the geologically similar material. The contaminant sources contained throughout a geologic unit possessed the shape of the geologic unit.

Two source lengths for the 216-Z-1A, 216-Z-18, and 216-Z-9 Cribs were evaluated in the models. For the evaluations imposing the lower recharge rates at the waste sites representing the two most probable surface end states, either surface revegetation or construction of an evapotranspiration (ET) barrier, the source length was assumed to equal twice the length of the surface dimension of the 216-Z-1A and 216-Z-9 Cribs parallel to the direction of groundwater flow (Figures E4-7 and E4-8, respectively). Section E4 provides the basis and rationale for this approximation. For the evaluations imposing the higher recharge rates representing continuation of current vegetation eradication practices or minimal recovery of native vegetation, the source length was assumed to equal the length of the surface dimension of the 216-Z-1A and 216-Z-9 Cribs parallel to the direction of groundwater flow. As neither of these options is considered a viable remedy option for the waste sites, the intent of these evaluations is to demonstrate, with the information currently available, that neither of these options appears to be capable of adequately protecting groundwater, even if the smaller estimate of the areal extent of contamination identified in Section E4 is used in the model. As surface revegetation or construction of an ET barrier represents the two most probable post-remediation surface end states, the intent of these evaluations is to provide a bounding estimate of the long-term effectiveness of these remedies.

For the 216-A-8 Crib model, contaminant sources are all point source types with a thickness of 1 m (3.3 ft). Three source lengths were evaluated in the 216-A-8 Crib model: one equal to the lengthwise dimension of the crib, the second equal to one-half of the lengthwise dimension of the crib, and the third equal to one-quarter of the lengthwise dimension of the crib (Figure E4-6). Figure 2-10 indicates that the contamination is limited to one-half of the length of the crib, but there are few data to provide the basis for this approximation.

Sampling results representing the contaminant point source locations, the contaminant locations comprised of geologically similar material, and the contaminant locations contained throughout a geologic unit were pooled and evaluated statistically to determine mean values, the upper 95 percent confidence limit of the mean, and the 90th percentile value of the data. In the cases where only one data point was available for a particular depth interval, the single data point value substituted for the upper 95 percent confidence limit of the mean and the 90th percentile value of the data. Where more than one data point was available for a particular depth interval but insufficient data were available to determine the upper 95 percent confidence limit of the mean, the 90th percentile value of the data substituted for the upper 95 percent confidence limit of the mean. Tables E4-3, E4-4, E4-5, and E4-6 present the results of the statistical analyses and the initial source term contaminant concentrations for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Crib models, respectively. The contaminant concentrations were assumed to be constant within the individual source depth intervals.

For the purpose of this evaluation, the conceptual model considers only the advective release of contaminants from the sediments. The release of contaminants is unlimited by any mechanisms that would restrain the release, such as solubility limits, metal precipitation, or contaminant sequestration from the advective flow path. All of the contamination in the source area is available for advective transport, and the release occurs according to the equilibrium K_d .

E5.3.4 Groundwater Domain and Characteristics

The groundwater domain and characteristics are very different in 200 East Area than they are in 200 West Area. The direction of groundwater flow around the 216-Z-1A and 216-Z-9 Cribs in 200 West Area is

generally west to east (DOE/RL-2008-66, *Hanford Site Groundwater Monitoring for Fiscal Year 2008*). The water table measures approximately 134.5 m (441 ft) in elevation NAVD88 (water level measured 134.4 m (440.9 ft) NAVD88 in March 2008 and 135 m (442.9 ft) in March 2009 NAVD88 in wells 299-W15-38 and 299-W15-42, respectively Hanford Virtual Library, available at: <http://vlprod.rl.gov/vlb/>). The groundwater table is expected to continue declining because the large discharges of operational liquid to the ground at 216-U-10 Pond and other large discharge sites in 200 West Area have ceased. For this modeling activity, a long-term average groundwater hydraulic gradient of 0.0011 (estimated from Figure 2-8 in WHC-EP-0645, *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds*). The aquifer, identified as Ringold Unit E – aquifer, is separated from that portion of the Ringold Unit E above the water table (Ringold Unit E – vadose), reflecting the distinctly different saturation conditions. Within the model domain, the aquifer extends to a depth of approximately 15 m (49 ft), but the model evaluates concentrations in the upper 5 m (16.4 ft) or 10 m (33 ft) of the aquifer. The horizontal saturated hydraulic conductivity for the aquifer is estimated to be 4.95 m/day (16 ft/day) based on the hydraulic properties presented in PNNL-14895, PNNL-15914, and PNNL-16198. Table E5-6 presents a summary of the aquifer hydraulic parameters for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs.

Table E5-6. Soil Hydraulic Properties for Aquifer Soil Type at 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Aquifer Soil Type	Bulk Density (g/cm)	Total Porosity	Saturated Moisture Content	Horizontal Saturated Hydraulic Conductivity ^{a,b} (m/day)	Longitudinal Dispersivity ^c (m)	Aquifer Hydraulic Gradient ^d (m/m)
Ringold Unit E Gravel (aquifer) (216-Z-1A and 216-Z-9)	2.07	0.077	0.077	4.95	1.9	1.1E-03
Ringold Gravel (Aquifer) (216-A-8)	1.93	0.280	0.167	1,000	1.9	1.0E-05

Notes:

Aquifer soil hydraulic properties adopted from PNNL-14895, PNNL-15914, PNNL-16198, and PNNL-14702, with the following exceptions:

- a. Horizontal Saturated Hydraulic Conductivity of Ringold Gravel (aquifer) (216-A-8) estimated from PNNL-14753.
- b. Vertical Saturated Hydraulic Conductivity assumed equal to 1/10 of the Horizontal Saturated Hydraulic Conductivity.
- c. Longitudinal Dispersivity calculated using Gelhar and Axness, 1983 equation; Transverse dispersivity assumed to be equal to 1/10 of the longitudinal dispersivity.
- d. Aquifer Hydraulic Gradient estimated from 1944 hindcast water table map (WHC-EP-0645).

Gelhar and Axness, 1983, "Three-Dimensional Stochastic Analysis of Macrodispersion in a Stratified Aquifer"

PNNL, 14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*

PNNL-14753, *Groundwater Data Package for Hanford Assessments*

PNNL-14895, *Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site*

PNNL-15914, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-9 Trench at the Hanford Site: Heterogeneous Model Development and Soil Vapor Extraction Modeling*

PNNL-16198, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and 216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*

WHC-EP-0645, *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds*

The direction of groundwater flow in the area around the 216-A-8 Crib in 200 East Area is difficult to determine (DOE/RL-2008-66). The water table elevation is approximately 122 m (400 ft) NAVD88 (e.g. the elevation in Well 299-E26-6 measured 121.9 m NAVD88 in 04/07/2009, Hanford Virtual Library, available at: <http://vlprod.rl.gov/vlib/>), but is expected to continue changing because the large discharges of operational liquid to the ground have ceased. Because of the uncertain nature of the flow direction and the changes expected to occur in the water table elevation, the 216-A-8 Crib is assumed to lay lengthwise parallel to the direction of groundwater flow. For this modeling activity, a long-term average groundwater hydraulic gradient of 0.00001 (estimated from the steady state gradient shown in Figure 2-8 in WHC-EP-0645) is assumed, with a groundwater table elevation of 122 m (400 ft) NAVD88. The aquifer, identified as Ringold Gravel - aquifer, is separated from that portion of the gravel above the water table (Ringold Gravel – vadose), reflecting the distinctly different saturation conditions. Within the model domain, the aquifer extends to a depth of approximately 15 m (49 ft) but the model evaluates concentrations in the upper 5 m (16.4 ft) or 10 m (33 ft) of the aquifer. The horizontal saturated hydraulic conductivity for the aquifer is estimated to be 1,000 m/day (3280 ft/day) based on the information presented in PNNL-14753, *Groundwater Data Package for Hanford Assessments*.

E5.3.5 Vadose Zone Hydrogeology and Transport

The flow and transport pathway process used for 216-Z-1A, 216-Z-9, and 216-A-8 Cribs zone modeling is porous media continuum flow. The vadose zone sediments at the Hanford Site are composed of sediments ranging in particle size associated with gravels to silts or clays. Porous media continuum transport in unsaturated media of this type is regarded as the fundamental process and feature for modeling contaminant fate and transport behavior in the vadose zone at the Hanford Site (DOE/RL-2007-34).

The hydraulic properties describing the water flow and retention characteristics associated with each of the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs area geologic layers are approximated by average values, with each unit having different flow and transport parameter values (Tables E5-7 and E5-8). PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, includes statistical summaries of measurements of the hydraulic properties for Hanford Site vadose zone sediments, and PNNL-14895, PNNL-15914, and PNNL-16198 include statistical summaries of measurements of the hydraulic properties for the vadose zone sediments around the 216-Z-1A and 216-Z-9 Cribs. The summary statistics include minimum, maximum, mean, standard deviation, and for hydraulic conductivity, mean and standard deviation of the natural log transforms of the data.

Estimates of longitudinal dispersivity for each of the hydrostratigraphic units were estimated using the Gelhar and Axness, 1983, “Three Dimensional Stochastic Analysis of Macrodispersion in a Stratified Aquifer,” stochastic solution:

$$A_L = \sigma_{\ln(K_s)}^2 \lambda$$

where:

A_L = longitudinal dispersivity (m or cm)

$\sigma_{\ln(K_s)}^2$ = the variance of the natural log of the saturated hydraulic conductivity measurements (dimensionless)

λ = vertical correlation scale (i.e., average distance over which conductivities are correlated) for log of the saturated hydraulic conductivity measurements (m or cm)

Table E5-7. Soil Hydraulic Properties for Vadose Zone Soil Types at 216-Z-1A and 216-Z-9 Cribs

Stratigraphic Unit	K ² (cm/s)	Porosity	van Genuchten α (1/cm)	van Genuchten n	Srl
Ringold A	5.73E-3	0.0770	0.0090	1.6210	0.1299
Lower Mud	1.16E-8	0.0770	0.0090	1.6210	0.1299
Ringold E	5.73E-3	0.0770	0.0090	1.6210	0.1299
Upper Ringold	5.73E-3	0.0770	0.0090	1.6210	0.1299
Cold Creek C	6.72E-3	0.3203	0.0173	1.7705	0.2451
Cold Creek Z	1.48E-4	0.4238	0.0052	2.0671	0.0967
Lower Sand	1.87E-2	0.3359	0.1338	2.0475	0.0747
Lower Gravel	3.00E-2	0.2720	0.0270	1.9940	0.1471
Hanford 2	5.85E-3	0.3653	0.0448	2.3553	0.0846
Hanford 1	5.00E-2	0.1660	0.0830	1.6600	0.1386
Hanford 1A	5.98E-4	0.4478	0.0107	1.9229	0.1740
Backfill	1.5E-2	0.2620	0.0320	1.4000	0.3646

Source: Excerpted from PNNL-16198, Table 4.5.

This stochastic model relates macrodispersive spreading to the spatial variability of saturated hydraulic conductivity in saturated porous media. The estimate of the correlation length, λ , is based on saturated hydraulic conductivity estimates collected at approximate 30 cm (12 in.) intervals for a depth of 18 m (59 ft) within the Hanford formation (RPP-17209, *Modeling Data Package for an Initial Assessment of Closure of the S and SX Tank Farms*). The fitted spherical variogram of the data suggests a correlation length of about 50 cm (20 in.) (see Figure D-1 in RPP-17209). However, as indicated by Russo, 1993, "Stochastic Modeling of Macrodispersion for Solute Transport in a Heterogeneous Unsaturated Porous Formation," the correlation scale is expected to decrease as the moisture content decreases, hence a smaller value (30 cm [12 in.]) is used to determine the dispersivities.

Longitudinal dispersivity also appears to be correlated with the model domain scale. The correlation between the dispersivity and the model domain scale appears to be approximately 1:10 (e.g. RPP-17209, Appendix D). Therefore, the dispersivity of any single unit was not allowed to exceed 1/10th of the sediment type's total thickness in the model. The thicknesses of the geologic units in the 216-Z-1A and 216-Z-9 model domains were determined based on the average thickness throughout the model domain. For the purpose of this calculation, the artificial division of Ringold – Vadose and – Aquifer was ignored. For most of the vadose zone geologic units in the 216-Z-1A and 216-Z-9 model domains, the 1/10th limitation dominated the determination of dispersivity coefficients (Table E5-9). Longitudinal dispersivity (i.e., in the direction of flow) is assumed to be 10 times larger than dispersivity in the transverse direction, which is consistent with the 10:1 anisotropy ratio of the hydraulic conductivity.

Table E5-8. Soil Hydraulic Properties for Vadose Zone Soil Types at 216-A-8 Crib

Soil Type	Bulk Density (g/cm³)	Total Porosity^a	Saturated Moisture Content	van Genuchten α (1/cm)	van Genuchten n	Residual Saturation	Residual Moisture Content^b	Vertical Saturated Hydraulic Conductivity^c (cm/s)	Longitudinal Dispersivity (m)^d
Backfill (B)	1.94	0.276	0.262	0.019	1.4	0.162	0.042	5.98E-04	0.6
Hanford H1 Coarse Sand (Hcs)	1.93	0.377	0.349	0.061	2.031	0.134	0.047	2.27E-03	1
Hanford H1 Gravelly Sand (Hgs)	1.94	0.276	0.238	0.014	2.12	0.14	0.033	6.65E-04	1.1
Hanford H2 Sand (Hfs)	1.49	0.403	0.379	0.027	2.168	0.162	0.061	3.74E-04	0.2
Hanford H2 Silty Sand (Hss)	1.61	0.445	0.445	0.008	1.915	0.159	0.071	8.85E-05	0.6
Hanford H3 Sandy Gravel (Hg)	1.93	0.280	0.167	0.017	1.725	0.134	0.022	3.30E-04	0.9
Plio-Pleistocene (PPIZ)	1.60	0.419	0.419	0.005	2.249	0.086	0.036	5.57E-05	0.4
Ringold Gravel - (vadose) (Hg)	1.93	0.280	0.167	0.017	1.725	0.134	0.022	3.30E-04	2.3

Notes:

Vadose zone soil hydraulic properties adopted from PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, with the following exceptions:

- a. Total porosity calculated from 1 – (bulk density/2.68 cm/g³).
- b. Residual Moisture Content calculated from Saturated Moisture Content Residual Saturation.
- c. Horizontal Saturated Hydraulic Conductivity is equal to 10 times the vertical saturated hydraulic conductivity (assuming an anisotropy ratio of 10:1), except for backfill soil types, for which the vertical and horizontal saturated hydraulic conductivities are equal.
- d. Longitudinal Dispersivity calculated using Gelhar and Axness, 1983, “Three-Dimensional Stochastic Analysis of Macrodispersion in a Stratified Aquifer,” equation. Transverse dispersivity equal to 1/10 of the longitudinal dispersivity.

Table E5-9. Dispersivity Values for Vadose Zone Soil Types at 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

	Standard Deviation	Variance	Vertical Correlation Scale (cm)	Layer Thickness Check (10%, m)	Longitudinal Dispersivity (m)		Transverse Dispersivity (m)	
					216-Z-1A	216-Z-9	216-Z-1A	216-Z-9
216-Z-1A and 216-Z-9								
Backfill	5.499	30.2	30	900	0.467	0.433	0.433	0.047
Hanford 1A	2.420	5.86	30	200	0.714	0.288	0.288	0.029
Hanford 1	3.322	11.0	30	350	0.935	1.180	0.935	0.118
Hanford 2	2.050	4.20	30	150	1.29	0.826	1.290	0.083
Lower Gravel	3.582	12.8	30	400	0.619	0.265	0.619	0.027
Lower Sand	1.960	3.84	30	100	0.829	0.952	0.829	0.095
Cold Creek Z	2.560	6.55	30	200	0.374	0.243	0.374	0.024
Cold Creek C	3.590	12.9	30	400	0.308	0.290	0.308	0.029
Upper Ringold	2.332	5.44	30	150	0.524	0.104	0.524	0.010
Ringold E	2.332	5.44	30	150	4.026	4.565	1.50	0.150
216-A-8								
Backfill	3.359	11.3	30	350	0.6	0.6	0.6	0.06
Hanford H1 Coarse Sand (Hcs)	1.721	2.96	30	100	4.0	1.0	1.0	0.10
Hanford H1 Gravelly Sand (Hgs)	2.290	5.24	30	150	1.1	1.1	1.1	0.11
Hanford H2 Sand (Hfs)	2.657	7.06	30	200	0.2	0.2	0.2	0.02
Hanford H2 Silty Sand (Hss)	1.885	3.55	30	100	0.6	0.6	0.6	0.06
Hanford H3 Sandy Gravel (Hg)	3.265	10.7	30	300	0.9	0.9	0.9	0.09
Plio-Pleistocene (PPz)	3.805	14.5	30	450	0.4	0.4	0.4	0.04
Ringold Gravel - (vadose) (Hg)	3.265	10.7	30	300	2.3	2.3	2.3	0.23

* Rounded to nearest 50 cm increment.

E5.3.6 Recharge

The magnitude of recharge for soils at the Hanford Site varies as a function of the soil type, condition of the vegetation cover, and soil integrity (e.g., disturbed versus undisturbed) (PNNL-13033, *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment*; PNNL-14744, *Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment*; PNNL 14702; PNNL-14725, *Geographic and Operational Site Parameters List [GOSPL] for Hanford Assessments*; and PNNL-16688, *Recharge Data Package for Hanford Single-Shell Tank Waste Management Areas*).

The range of recharge values reported in these documents represents distinct populations of data based on lysimetry and isotopic measurements, and interpretation, and in some instances extrapolation, by Hanford Site subject matter experts. The natural background recharge rates represent a population for natural vegetated conditions. The range of values for operational, pre-remediation conditions represents a population of recharge rates for vegetation-free disturbed soil (sand).

The most appropriate soil type for estimates of recharge rates in the 200 West and 200 East Areas of the Hanford Site Central Plateau is the variety of Rupert sand appropriate for that area (PNNL-14702, PNNL-14725). The recharge rates representing the pre-operational natural soil conditions and the 55-year operational period prior to remedy implementation (1949 though 2020 for the 216-Z-1A Crib, 1955 though 2020 for the 216-Z-9 Crib, and 1955 though 2016 for the 216-A-8 Crib) are 4 mm/yr and 63 mm/yr, respectively. The most recent estimate of long term recharge through Rupert Sand surfaces with a shrub-steppe plant community is 1.7 mm/yr (PNNL-16688), so the estimate of 4 mm/yr (from PNNL-14725) may be considered to be conservatively biased. The recharge rates were selected from the range of values reported as appropriate for the various soil types and conditions at the Hanford Site (e.g., PNNL-14702, PNNL-14725).

The most appropriate surface condition for waste sites that undergo backfilling and post-remediation re-vegetation is young shrub-steppe plant community that develops and matures (PNNL-14725, DOE/RL-2007-34). The long term post-remediation recharge rate estimate of 4 mm/yr is based on estimated values of long term recharge rates (LTRRs) for all Hanford Site soil types (PNNL-14702, PNNL-14725, PNNL-16688). The estimates provided in PNNL-14702 and PNNL-14725 indicate that for post-remedy LTRR, a post-remediation value of 8 mm/yr should be used for the first 30 years after site closure, followed by the value of 4 mm/yr thereafter. This long-term value is more than twice the estimate in PNNL-16688 for long-term recharge rate through Rupert Sand surfaces with a shrub-steppe plant community, so the estimate of long-term post-remediation recharge rate may be considered to be conservatively biased. The applicability of these recharge rates include the inherent assumption that the natural shrub-steppe vegetation cover reclaims the ground surface. In the case representing no action beginning present day (2010), only shallow rooted vegetation is assumed to revegetate the surface and the long-term recharge rate is estimated to be 22 mm/yr (PNNL-14702, PNNL-14725). Table E5-10 presents LTRRs for each of the pre-operational, operational, post-operational, and classes for the Rupert sand soil type used in the modeling and evaluation.

The modeling assumptions and parameter estimates used here are based on the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs site-specific conditions, which may differ from those used for other Hanford Site modeling performed for different purposes, areas, or scales. The recharge rate estimates selected for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs site-specific conditions and therefore will differ from those used for modeling at other scales because the most representative values appropriate for these modeling efforts involve different population(s) of recharge rate.

Table E5-10. Recharge Rates for Surface Soil and Vegetation Types at 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Waste Site Surface Condition	Period of Time	Recharge Rate
Undisturbed Rupert sand with shrub-steppe plant community (natural condition)	Pre-Operational Period	4 mm/yr
Hanford sand - disturbed, with no vegetation	Operational period: 216-Z-1A: 1949 through 2020 216-Z-1A: 1955 through 2020 216-A-8: 1955 through 2016	63 mm/yr
Rupert sand - disturbed, with shallow rooted vegetation only	Present day (2010) forward*	22 mm/yr
Rupert sand-with young shrub-steppe plant community	Post-Remediation Period (30 years)	8 mm/yr
Long-Term Post-Remediation Rupert sand-with mature shrub-steppe plant community	Post-Remediation (after 30 years)	4 mm/yr
Evapotranspiration barrier	Post-Remediation Period (500 years)	0.5 mm/yr
Evapotranspiration barrier	Post-Remediation Period (after 500 years)	1.0 mm/yr

* For the purpose of evaluating the no action alternatives, current vegetation removal practices are assumed to end immediately

E5.3.7 Geochemistry

The geochemistry conceptual model component for the modeling involves the technical basis and rationale for the specific contaminant partitioning behavior regarding release, retardation, and attenuation mechanisms, and any simplifying assumptions. The key aspects of this geochemistry conceptual model include the following, which are discussed in detail in DOE/RL-2007-34:

- The rationale for the simplifying assumption that the use of a linear K_d isotherm is a reasonable conservative description for the release and attenuation of contaminants in the context of providing an upper-bounding condition
- The rationale and source(s) of the data used in the selection of contaminant K_d values
- The rationale for the use of a single K_d for all vadose zone units

The geochemistry conceptual models for the Hanford Site are based on extensive laboratory studies, testing, and measurements involving Hanford Site-specific sediments, contaminants, and conditions performed using batch and column tests in measurements of adsorption and desorption coefficients under saturated and unsaturated conditions (e.g., PNNL-13895, *Hanford Contaminant Distribution Coefficient Database and Users Guide*; PNNL-11966, *Radionuclide Distribution Coefficients for Sediments Collected from Borehole 299-E17-21: Final Report for Subtask 1a*; PNNL 13037, *Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment*; PNNL-15502, *Characterization of 200-UP-1 Aquifer Sediments and Results of Sorption-Desorption Tests Using Spiked Uncontaminated Groundwater*; and PNNL-15121, *Uranium Geochemistry in Vadose Zone and Aquifer Sediments from the 300 Area Uranium Plume*). Chapter E3.0 presents the basis and rationale for the K_d values used to approximate the contaminant transport of the COPCs. Table E5-11 presents the values.

Table E5-11. Contaminant K_d Values Used in the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs Models

Contaminant	K_d (mL/g)	Contaminant	K_d (mL/g)
1,1,2,2-Tetrachloroethane	0.05	Methylene chloride	0.01
1,1,2-Trichloroethane	0.05	Tetrachloroethene	0.25
1-Butanol	0.01	Trichloroethene	0.1
Benzene	0.05	Carbon-14	0
Bromodichloromethane	0.05	Radium-238	3
Bromoform	0.1	Technetium-99	0
Carbon tetrachloride	0.15	Hexavalent chromium	0
Chloroform	0.05	Nitrate/Nitrite as N	0
Ethylbenzene	0.2		

E5.3.8 Point of Calculation, Protectiveness Metric, and Timeframe Considerations

In accordance with risk assessment guidelines, the determination of soil contamination impacts to groundwater also requires the definition and rationale for the following:

- The Point of Calculation (POCal) i.e., the place/point in the groundwater domain where modeled groundwater concentrations are to be assessed for potential impacts and protectiveness
- The protectiveness metric, i.e., the groundwater metric(s) to be used in the assessment of protectiveness at the POCal
- The timeframe considered applicable for the calculation of impacts to groundwater

The POCal for the protection of groundwater is related to the “Exposure Point” in the context of conventional human health risk assessments (EPA/540/1-89/002) and to “Point of Compliance” in federal and state regulations and guidelines (DOE/RL-2007-34). The POCal is intended to effectively serve as the point where exposure point groundwater concentrations are evaluated in the model for evaluating protectiveness.

The POCal used for the modeling results was the location according to the model results where maximum concentrations in groundwater occurred during the evaluation period. This aspect of the model methodology requires consideration of the model results as a function of distance downgradient in order to determine the POCal that yields the highest peak concentrations within the groundwater. As calculated in the model, lateral flow caused by the geologic stratigraphy and the contrast between the vertical and horizontal transport in the capillary fringe results in the maximum concentrations occurring downgradient from the waste site. For this evaluation, output groundwater concentrations were calculated at the edge of the waste site and at 10, 20, 30, 40, 60, and 100 m (33, 66, 98, 131, 197, and 328 ft) downgradient from the waste site.

The aquifer-mixing zone extended over the upper 5 and 10 m (16 and 33 ft) of the aquifer for the purpose of the evaluations. The 5 m (16 ft) vertical interval corresponds to a conceptual groundwater monitoring well with the 4.6 m (15 ft) well screen length (and mixing zone dimension) associated with state monitoring well descriptions (e.g., see WAC 173-340-747). The 10 m (33 ft) vertical interval corresponds to a conceptual groundwater production well with the 9.1 m (30 ft) well screen length (and mixing zone dimension), which is consistent with the experience at the 200-ZP-1 OU pump-and-treat system.

To account further for the capillary fringe effects, the evaluation included two bases for calculating groundwater concentration. The first basis included only the upper 5 or 10 m (16 or 33 ft) of the aquifer rows in the groundwater concentration calculations, the second included the first row of the capillary fringe with the upper 5 or 10 m (16 or 33 ft) of the aquifer rows. The highest calculated concentration from either basis was used in the evaluation of impacts to groundwater.

The protectiveness metrics determined to be most appropriate for the evaluation of impacts to groundwater from vadose zone contamination at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs were the MCLs, except in the case of CT, which adopted the slightly more stringent cleanup level identified in EPA et al., 2008, *Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington*. Use of the MCLs as a protectiveness metric for groundwater is consistent with the intent of an effective "no growth" policy for groundwater contamination. In this context, the MCLs represent the "allowable concentrations" and/or "acceptable limits" of a contaminant for minimizing further degradation of groundwater in accordance with the conditions identified in state and federal anti-degradation goals (e.g., EPA/540/R-92/003, *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual [Part B, Development of Risk-Based Preliminary Remediation Goals, Interim]*; EPA/530-SW-87-017, *Alternate Concentration Limit Guidance*; and DOE/RL 2002-59). Additional reasons for the selection of the MCLs included the following:

- They are metrics appropriate for a reasonable maximum exposure scenario in groundwater (i.e., potential future drinking water source).
- Their use is consistent with federal risk assessment guidance (EPA/540/R-92/003), and federal regulatory requirements and guidelines for the establishment of media-specific cleanup levels (40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan"; CERCLA; and EPA/530-SW-87-017).
- Their use is consistent with the stated goals in the Hanford Site Groundwater Strategy (DOE/RL-2002-59).
- They are appropriate metrics for identifying waste-site scale impacts to groundwater.

Defining the protection of groundwater in the context of vadose zone fate and transport requires consideration of the soil and groundwater media as a hybrid or coupled pathway. This pathway involves the determination of future concentrations in the groundwater medium that result from the transport of contamination currently existing in the soil medium. Therefore, the working definition of protectiveness for the protection of groundwater pathway at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs was considered achieved if the contaminant levels in the vadose zone soil do not cause groundwater concentrations to exceed MCLs at the POCal within the specified timeframe. The timeframe for the evaluation period is limited to 1,000 years after remediation, which is assumed to begin in 2020 at 216-Z-1A, 216-Z-18, and 216-Z-9 and 2016 at 216-A-8.

E5.3.9 Uncertainties, Assumptions, and Conservatisms

Potential sources of uncertainty in risk assessments are primarily in the categories of (a) model uncertainties, (b) scenario uncertainties, and (c) parameter uncertainties. Model uncertainty pertaining to the equations used as numerical representations of the natural processes is expected to be relatively small. DOE/RL-2007-34 provides a summary evaluation of the comparisons of field data and field test results to corresponding model results obtained using the STOMP code, and the evaluation indicates that the equations used in STOMP adequately simulate the natural processes. The technical basis regarding scenario and parameter selection and the evaluation of uncertainty and variability is also documented in DOE/RL-2007-34 and in the conceptual model sections discussed previously. Documentation is provided

in Sections 4.0 and 5.0 of DOE/RL-2007-34 on (a) dominant model factors, (b) model parameter values and plausible ranges of parameter values, (c) model assumptions and their effects on model results, and (d) model limitations. The results of the sensitivity analyses are intended to address parameter uncertainty and the impact of certain assumptions on the model results. It is notable that the main categories of factors that dominate model results identified in DOE/RL-2007-34 are the same as those identified in the evaluation of model assumptions, sensitivity analyses, and model limitations for the 200-PW-1, 200-PW-3, and 200-PW-6 OU modeling. It is further indicated from the uncertainty analysis that the conservatism in the model assumptions, together with conservatism in parameter values, contribute to a conservative bias in the model results overall (i.e., higher maximum concentrations in groundwater).

An evaluation of the primary assumptions associated with this vadose zone modeling approach at the Hanford Site is summarized in Table 5-3 in DOE/RL-2007-34. The evaluation of these assumptions indicates that (a) most of the assumptions involve hydrogeologic and geochemical factors, (b) most of the assumptions are either conservative or neutral, (c) source-term uncertainty is potentially non-conservative, and (d) the majority of conservative assumptions range from moderate to high magnitudes in terms of their potential effect on risk and vadose zone model results. The evaluation of these assumptions indicates that, with the exception of the source-term uncertainty, the assumptions associated with model parameterization are largely conservative. The assumptions identified as non-conservative or neutral are associated with the ability to approximate the geology in a finite difference grid, the applicability of the porous media continuum to water flow in the vadose zone, and the hydrogeologic parameterization of the main stratigraphic units. The magnitude of the effect of these assumptions on risk estimates is identified in DOE/RL-2007-34 as neutral or low. Based on the assumptions evaluation, results of vadose zone modeling for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs should provide conservative estimates of risk in terms of impacts to groundwater from soil contaminants.

E5.3.10 Numerical Solution Limitations

Results determined using numerical models will possibly be influenced by numerical dispersion, which is an artifact of the errors caused by the numerical discretization of the flow domain. To minimize these errors, the grid should be designed so that the Peclet Number, the ratio of the grid cell length and the dispersivity, is less than 1. However, maintaining this criterion can lead to grid spacing and an overall domain size that are not practical to implement. The grid size selected for the model appeared to provide an adequate balance between the two demands of solution integrity and practical implementation. The 1 m (3.3 ft) vertical spacing in the 216-A-8 model and the 0.5 m (1.6 ft) vertical spacing in the 216-Z-1A and 216-Z-9 models were sufficiently small to allow delineation of the major geologic units and the sloping of the contacts, and accommodate the 5 and 10 m (16 and 33 ft) well screen intervals used to evaluate the impacts to groundwater.

E5.4 Model Results

The following sections describe the boundary evaluation, screening analysis, reference case and sensitivity analysis used in the evaluations.

E5.4.1 Boundary Evaluation

The location of the side boundaries of the model domain is intended to prevent artificial boundary conditions from interfering with the solution of the model in the area of interest. This premise is confirmed by the results of the modeling from the period 1955 through 2010, which includes the high volume discharges at the cribs. Figures E5-3, E5-4, and E5-5 present a time series plots of moisture content during the period 1944-2010 for three selected locations near the downgradient boundary of the 216-Z-1A, 216-Z-9, and 216-A-8 Crib models, respectively. These locations in the model coincide with

stratigraphic unit changes in the model where pronounced lateral flow is most likely to occur. The results presented in the time series plots indicate that the calculations may have included some boundary effects due to the high volume discharges to the 216-A-8 Crib infringing upon the boundaries of the model.

No boundary effects appear to have occurred in the 216-Z-1A and 216-Z-9 Cribs models. Figure E5-6 presents profiles of the moisture content changes for three key times during the discharge period of the 216-A-8 Crib. These profiles indicate that the changes in the moisture content at the boundary of the model occur relatively early during the simulation period (ca. 1958) and are contained within a relatively small segment along the boundary near the water table and appear to be minor. These effects are considered minimal and have dissipated by the year 2010 in the model calculations. Consequently, they are not considered to effect adversely the evaluation of contaminant transport and groundwater impacts associated with contamination in the vadose zone at the 216-A-8 Crib, which begins in year 2010.

E5.4.2 Screening Analysis

Based on the screening model results, contaminants with K_d values greater than a particular value can be screened from further evaluation because they do not arrive in groundwater within 1,000 years. At the 216-Z-1A and 216-Z-18 Cribs, the screening analysis results indicate that contaminants with K_d values greater than 2.9 mL/g do not arrive in groundwater within 1,000 years and can be screened from further evaluation (Table E5-12).

At the 216-Z-9 Crib, the screening analysis results indicate that contaminants with K_d values greater than 1.2 mL/g do not arrive in groundwater within 1,000 years and can be screened from further evaluation (Table E5-13). Radium-228 can also be screened out because of the travel time to groundwater from a depth of 59.4 m (195 ft) bgs and the short half-life of the radionuclide (5.8 years, ANL, 2007, *Radiological and Chemical Fact Sheets to Support Health Risk Analyses for Contaminated Areas*). The difference in the screening results between the two cribs is the distance between the water table and the Cold Creek Carbonate unit. In the 216-Z-1A model, the bottom of the Cold Creek Carbonate unit is approximately 8 m (26 ft) closer to the water table than it is in the 216-Z-9 model. At the 216-A-8 Crib, the screening analysis results indicate that contaminants with K_d values greater than 0.8 mL/g do not arrive in groundwater within 1,000 years and can be screened from further evaluation (Table E5-14).

E5.4.3 Reference Case

The results of modeling provide an indication of the effectiveness of the different surface remedy alternatives in achieving protection of groundwater at 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs. For these evaluations, the average soil concentration value was considered to be the best estimate for the source terms. EPA guidelines indicate that vadose zone models used to estimate exposure point concentrations should utilize best estimate values for model parameters (EPA 540-R-02-002, *Risk Assessment Guidance for Superfund: Volume III – Part A, Process for Conducting Probabilistic Risk Assessment*). The guidelines indicate that the intent of risk characterization is to estimate the average chemical exposure point concentration, therefore the average soil concentrations appear to be the best estimate values for this purpose. Use of the average soil concentration values in the evaluations also appears to be consistent with WAC 173-340-740(7)(c)(4)(B), “Unrestricted Land Use Soil Cleanup Standards,” which states that the true mean soil concentration shall be used to evaluate compliance with cleanup levels for cleanup levels based on chronic or carcinogenic threats. However, parameters associated with the contaminant source term quantity, extent, and depth are highly variable and are usually based on limited data. Consequently, they are significant sources of uncertainty in the model results. Therefore, in addition to the results developed based on the average soil concentration values, the results developed based on the 95 percent upper confidence limit on the mean, and the 90th percentile value are also presented.

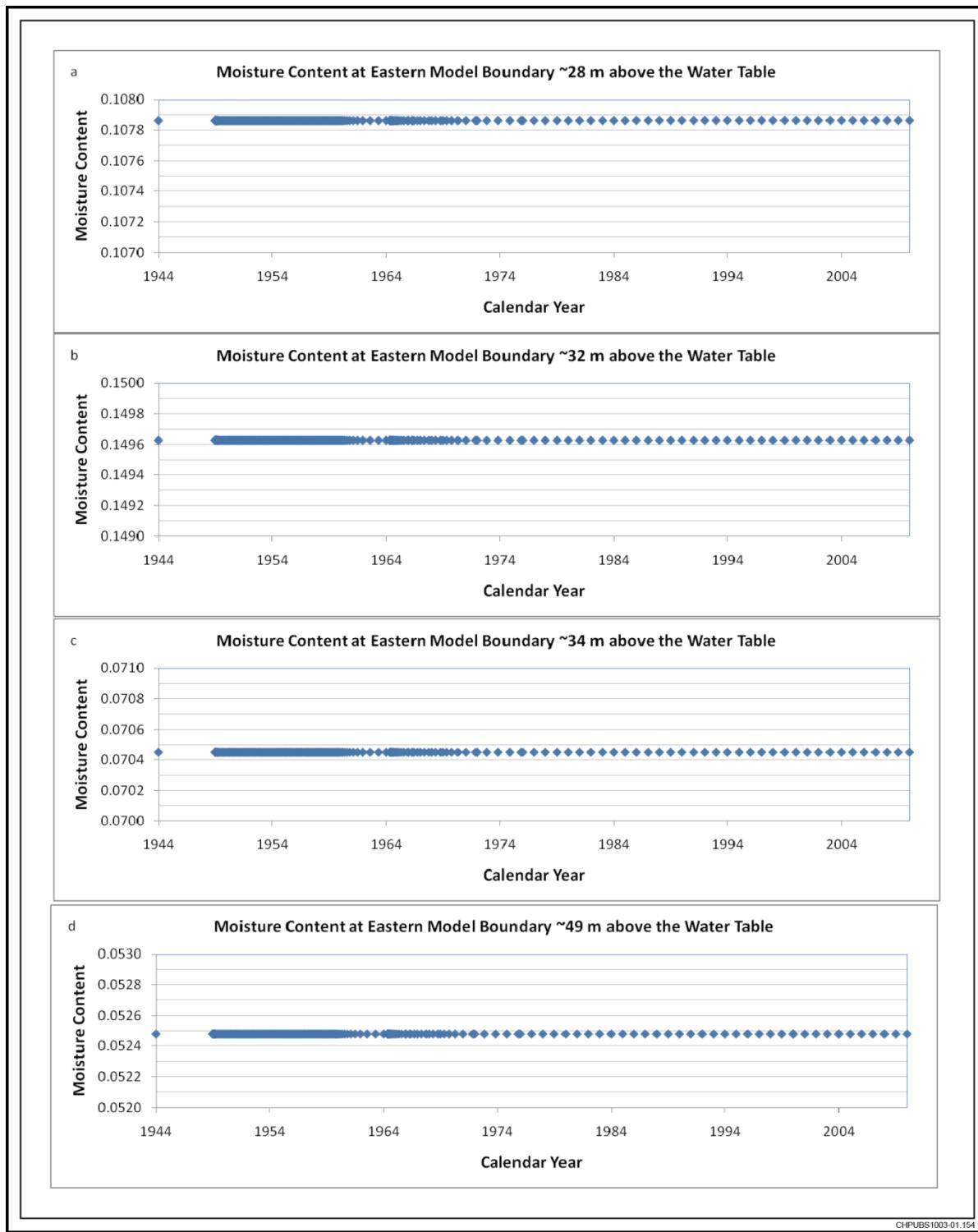


Figure E5-3. Time Series Plots of Moisture Content During the Period 1944-2010 for Four Selected Locations near the Downgradient Boundary of the 216-Z-1A Crib Model: (a) at the PPIc - RUE Interface 28 m (92 ft) Above the Water Table, (b) at the PPIz - PPIc Interface 32 m (105 ft) Above the Water Table, (c) at the Lower Sand - PPIz Interface 34 m (111 ft) Above the Water Table, and (d) at the H1 – H2 Interface 49 m (161 ft) Above the Water Table

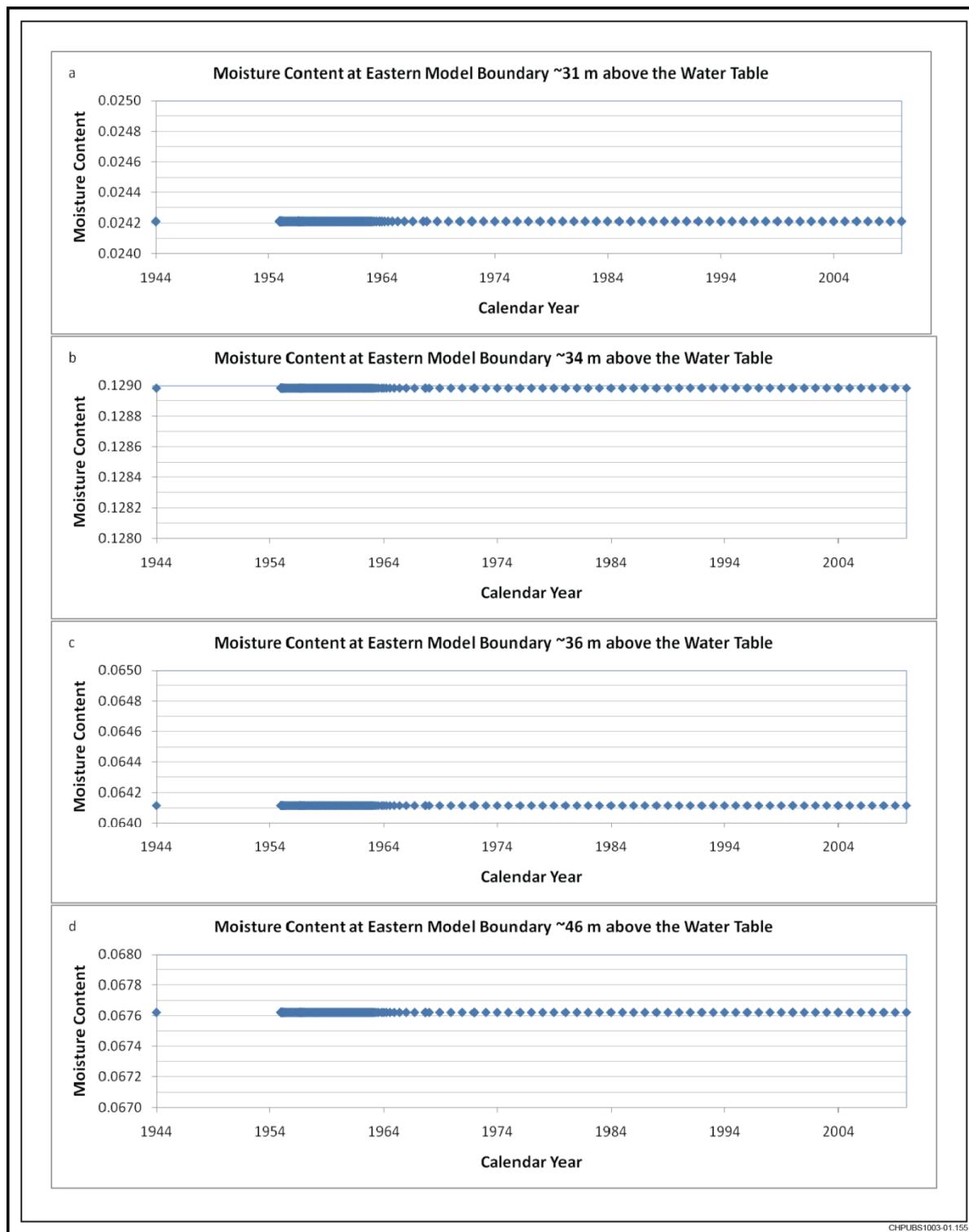


Figure E5-4. Time Series Plots of Moisture Content During the Period 1944-2010 for Four Selected Locations Near the Downgradient Boundary of the 216-Z-9 Crib Model (a) at the PPIc – Ringold Mud Unit Interface 31 m (102 ft) Above the Water Table, (b) at the PPIz - PPIc Interface 34 m (111 ft) Above the Water Table, (c) at the Lower Sand - PPIz Interface 36 m (118 ft) Above the Water Table, and (d) at the H2 – Lower Sand Interface 46 m (151 ft) Above the Water Table

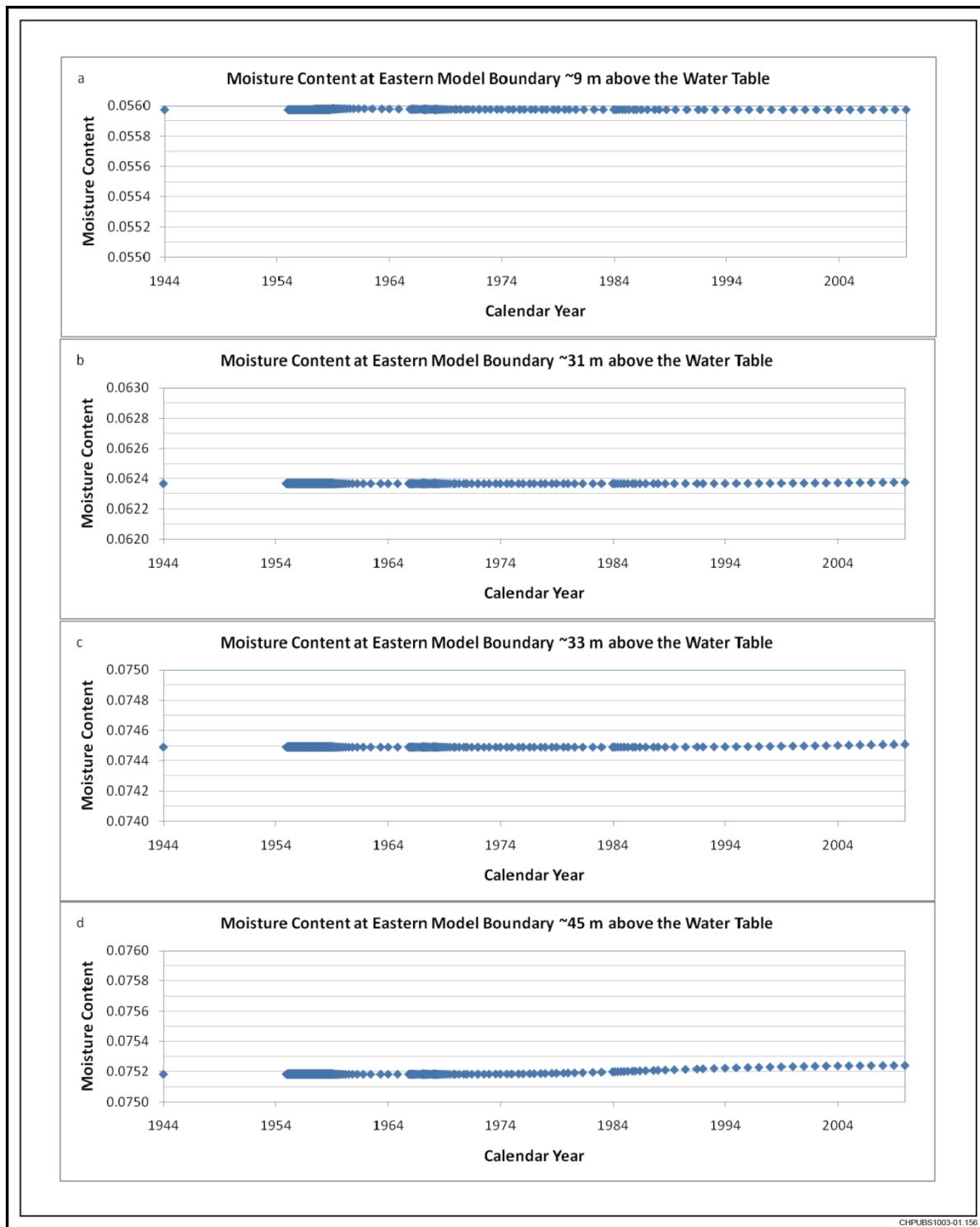


Figure E5-5. Time Series Plots of Moisture Content During the Period 1944-2010 for Four Selected Locations Near the Downgradient Boundary of the 216-A-8 Crib Model; (a) at a Hgs - Hcs Interface 9 m (29 ft) Above the Water Table, (b) at a Hcs - Hss Interface 31 m (102 ft) Above the Water Table, (c) at a Hcs - PPIz Interface 33 m (108 ft) Above the Water Table, and (d) at a Hcs - PPIz Interface 45 m (147 ft) Above the Water Table

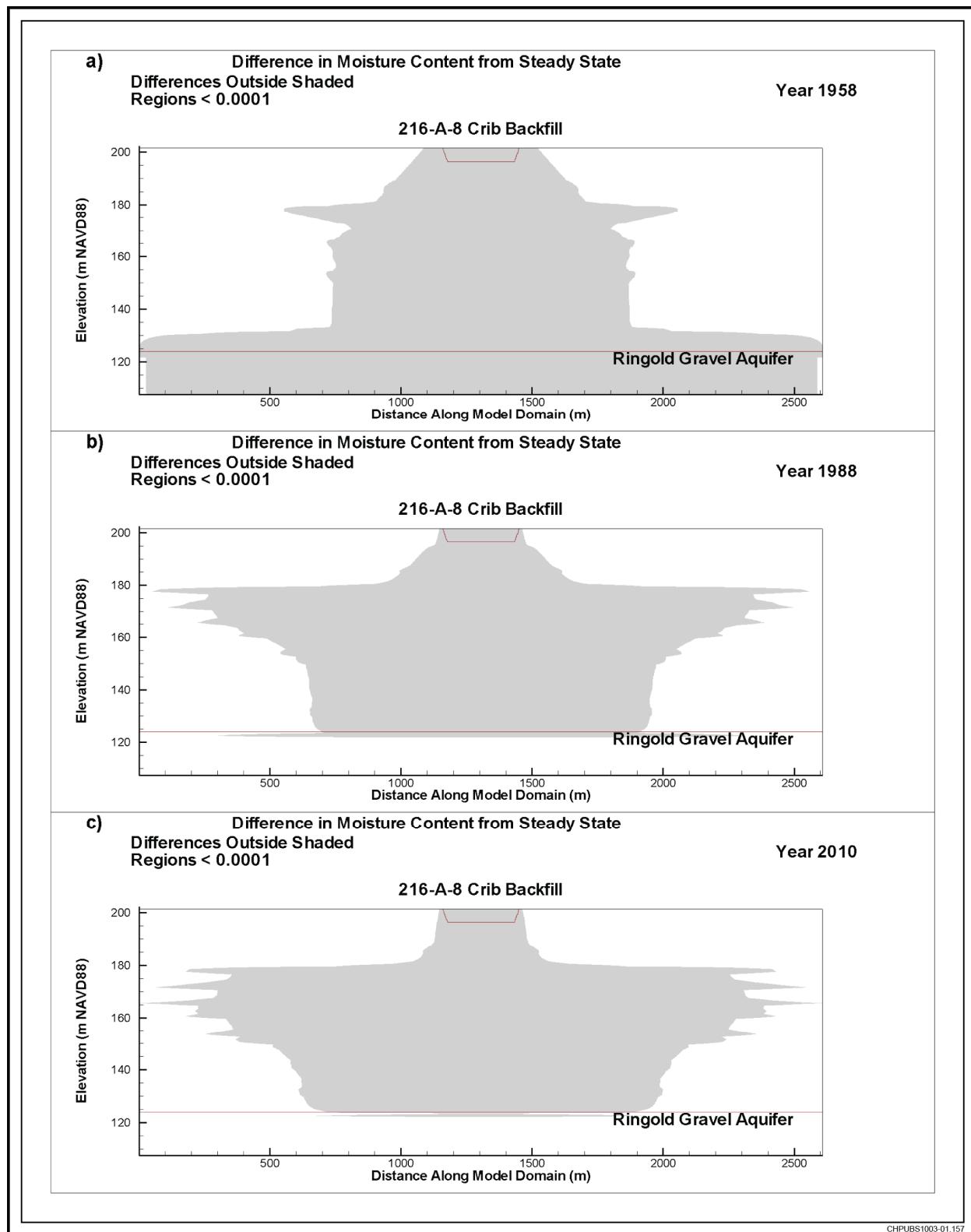


Figure E5-6. Moisture Content Profiles of the 216-A-8 Crib Model Domain During the Period of 1944 to 2010 for Three Selected Times

Table E5-12. Results of 216-Z-1A Crib Contaminant Screening Analysis

Contaminant K _d (mL/g)	Years to First Non-Zero Concentration Arrival at Water Table	Arrival < 1,000 Years?
216-Z-1A Maximum Depth of Contamination Cold Creek Carbonate		
Post-Remediation Long-Term Recharge Rate 4 mm/yr		
0.26	42	Yes
0.60	321	Yes
1.2	1,022	No
1.9	1,847	No
Post-Remediation Long-Term Recharge Rate 22 mm/yr		
0.26	54	Yes
0.60	177	Yes
1.2	397	Yes
1.9	656	Yes
2.8	994	Yes
2.9	1,031	No

Notes:

Results also applicable to 216-Z-18.

Table E5-13. Results of 216-Z-9 Crib Contaminant Screening Analysis

Contaminant K _d (mL/g)	Years to First Non-Zero Concentration Arrival at Water Table	Arrival < 1,000 Years?
216-Z-9 Maximum Depth of Contamination Cold Creek Carbonate		
Post-Remediation Long-Term Recharge Rate 4 mm/yr		
0.26	307	Yes
0.60	997	Yes
1.2	2,257	No
1.9	3,758	No
Post-Remediation Long Term Recharge Rate 22 mm/yr		
0.26	188	Yes
0.60	479	Yes
1.2	1,000	Yes
1.9	1,618	No

Table E5-14. Results of 216-A-8 Crib Contaminant Screening Analysis

Contaminant K_d (mL/g)	Years to First Non-Zero Concentration Arrival at Water Table	Arrival < 1,000 Years?
216-A-8 Maximum Depth of Contamination 15.7 m (51.5 ft) bgs		
Post-Remediation Long Term Recharge Rate 4 mm/yr		
0.1	449	Yes
0.8	4,123	No
1	5,158	No
Post-Remediation Long Term Recharge Rate 22 mm/yr		
0.1	155	Yes
0.8	1,025	No
1	1,275	No

The modeling results for the 216-Z-1A Crib indicate that with natural vegetation reestablished on the surface, the maximum concentrations of most, but not all, of the contaminants of potential concern do not exceed the MCL within 1,000 years (Table E5-15). The results of the modeling indicate that the maximum concentrations in groundwater of CT, methylene chloride, and nitrogen as nitrate and nitrite do exceed the respective MCLs within the 1,000-year evaluation period. Even if no efforts to reestablish natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the surface (i.e., recharge remains 22 mm/yr indefinitely), the modeling results indicate that only the maximum concentrations of those three COPCs at 216-Z-1A exceed the MCL within 1,000 years.

Table E5-15. Results of 216-Z-1A Crib Contaminant Fate and Transport Modeling Contaminant Concentrations in Groundwater

Contaminant	K_d (mL/g)	MCL ($\mu\text{g/L}$)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 0.5 mm/yr; Source Length = 2 x Length of Waste Site								
1,1-Dichloroethane	0.05	NP ^a	0.7	0.4	1.9	1.2	1.7	1.0
Carbon tetrachloride	0.15	3.4 ^b	2.6	1.5	3.0	1.8	3.1	1.9
Chloroform	0.05	80 ^c	1.7	1.1	4.2	2.6	4.5	2.8
Methylene chloride	0.01	5	110	74	160	100	180	120
Tetrachloroethene	0.25	5	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04
Trichloroethene	0.10	5	0.1	0.08	0.3	0.2	0.3	0.2
Nitrogen as nitrate and nitrite	0	10,000	11,700	7,600	30,200	19,600	24,600	16,000

**Table E5-15. Results of 216-Z-1A Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K_d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
Post-Remediation Long Term Recharge Rate 4 mm/yr; Source Length = 2 x Length of Waste Site								
Contaminant	K_d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	5 m	10 m	5 m	10 m	5 m	10 m
1,1-Dichloroethane	0.05	NP ^a	1.0	0.7	2.7	1.7	2.5	1.6
Carbon tetrachloride	0.15	3.4 ^b	13	7.3	16	9.4	17	9.8
Chloroform	0.05	80 ^c	2.4	1.5	5.6	3.5	6.1	3.8
Methylene chloride	0.01	5	150	97	210	130	240	160
Tetrachloroethene	0.25	5	5E-04	3E-04	0.002	9E-04	0.001	8E-04
Trichloroethene	0.10	5	0.5	0.3	1.1	0.7	1.1	0.6
Nitrogen as nitrate and nitrite	0	10,000	16,100	10,400	41,100	26,600	33,500	21,700
Post-Remediation Long Term Recharge Rate 22 mm/yr								
1,1-Dichloroethane	0.05	NP ^a	1.7	1.0	4.7	2.8	4.2	2.5
Carbon tetrachloride	0.15	3.4 ^b	80	47	130	77	140	85
Chloroform	0.05	80 ^c	4.6	2.7	11	6.5	12	6.9
Methylene chloride	0.01	5	220	130	320	200	370	220
Tetrachloroethene	0.25	5	0.4	0.2	1.0	0.6	1.0	0.6
Trichloroethene	0.10	5	1.3	0.8	3.1	1.8	3.1	1.8
Nitrogen as nitrate and nitrite	0	10,000	22,900	13,700	58,700	35,000	47,900	28,600
Post-Remediation Long Term Recharge Rate 63 mm/yr								
1,1-Dichloroethane	0.05	NP ^a	4.4	2.7	12	7.1	11	6.4
Carbon tetrachloride	0.15	3.4 ^b	190	120	320	190	350	210
Chloroform	0.05	80 ^c	11	6.4	26	16	28	17
Methylene chloride	0.01	5	550	320	800	480	920	550
Tetrachloroethene	0.25	5	1.1	0.7	2.6	1.6	2.7	1.6
Trichloroethene	0.10	5	3.2	1.9	7.4	4.4	7.6	4.5
Nitrogen as nitrate and nitrite	0	10,000	54,800	32,300	140,000	82,100	114,000	67,000

**Table E5-15. Results of 216-Z-1A Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K_d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Notes:								
216-Z-1A Crib is approximately 53 m (174 ft) long. 1,000-year timeframe.								
a. There is non-published (NP) EPA MCL specifically for 1,1-dichloroethane; there is a published EPA MCL for 1,2-dichloroethane (5 $\mu\text{g}/\text{L}$).								
b. The EPA MCL for CT is 5 $\mu\text{g}/\text{L}$; the final cleanup level in the 200-ZP-1 Record of Decision is 3.4 $\mu\text{g}/\text{L}$ (EPA et al., 2008, <i>Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington</i>).								
c. The EPA MCL for total trihalomethanes, which include bromodichloromethane, bromoform, and chloroform, is 80 $\mu\text{g}/\text{L}$.								

The modeling results for the 216-Z-18 Crib indicate that with natural vegetation reestablished on the surface, only the maximum concentrations of methylene chloride and nitrogen as nitrate and nitrite from the list of contaminants of potential concern exceed the MCL within 1,000 years (Table E5-16). If the long-term post-remediation recharge rate remains 22 mm/yr indefinitely, the modeling results indicate that the maximum concentrations in groundwater of CT and tetrachloroethene also exceed the MCL within 1,000 years.

The modeling results for the 216-Z-9 Crib indicate that with natural vegetation reestablished on the surface, only the maximum concentrations of Tc-99 and nitrogen as nitrate and nitrite from the list of contaminants of potential concern exceed the MCL within 1,000 years (Table E5-17). If the long-term post-remediation recharge rate remains 22 mm/yr indefinitely, the modeling results indicate that the maximum concentration in groundwater of CT also exceeds the MCL within 1,000 years.

The results of the modeling indicate that the contamination at 216-A-8 Crib may not require any specific remedial action to achieve the protection of groundwater (Table E5-18). Because there are few data to provide the basis for the approximation of the length dimension of the contamination source in the vadose zone, three contamination source lengths were evaluated in the 216-A-8 Crib model (Figure E4-26):

- Equal to the lengthwise dimension of the crib
- Equal to one-half of the lengthwise dimension of the crib
- Equal to one-quarter of the lengthwise dimension of the crib

With natural vegetation reestablished on the surface, the model results indicate that the maximum groundwater concentrations of all of the contaminants of potential concern remain less than the MCL during the 1,000-year evaluation period for contamination source lengths up to the entire length of the crib. If no efforts to reestablish natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the surface (i.e., recharge remains 22 mm/yr indefinitely), the maximum groundwater concentrations of carbon-14 and Tc-99 do exceed the MCL for contamination source lengths greater than one-half of the lengthwise dimension of the crib.

E5.4.4 Sensitivity Analysis

The parameter uncertainty discussion in DOE/RL-2007-34 included vadose zone parameter sensitivity analyses from Hanford Site and non-Hanford Site sources. The results of the analyses indicate that vadose zone model results consistently have the greatest sensitivity to variability in infiltration/recharge rate, unsaturated zone thickness, and contaminant K_d . For this reason, the sensitivity analysis for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs included multiple contaminant distributions and inventory masses, multiple post-remediation recharge rate scenarios.

Comparable post-remediation long-term recharge rate scenarios were considered at all of the cribs. The reference cases adopted the recharge rate considered to be most applicable to waste sites that undergo backfilling and either no shrub re-vegetation or post-remediation shrub re-vegetation. The sensitivity analyses included scenarios representative of the installation and effective performance of an ET surface barrier that limits percolation of precipitated water by storage and ET processes. The no shrub re-vegetation and ET surface barrier cases are considered to be the upper and lower bounding cases for post-remediation long term recharge rates. The results of the ET surface barrier sensitivity cases are presented and discussed in the context of the effectiveness of the barrier in reducing the maximum concentration in groundwater of those COPCs for which the reference case results exceed the MCLs. An additional sensitivity analysis, representative of the cribs being actively maintained free of vegetation indefinitely into the future, was also included solely for the purpose of comparison. The tables provide the results.

**Table E5-16. Results of 216-Z-18 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K_d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 0.5 mm/yr; Source Length = 2 x Length of Waste Site								
Benzene	0.05	5	0.06	0.04	0.1	0.09	0.1	0.1
Carbon tetrachloride	0.15	3.4 ^a	0.3	0.1	0.4	0.3	0.5	0.3
Chloroform	0.05	80 ^b	0.4	0.2	0.8	0.5	0.5	0.3
Ethylbenzene	0.20	700	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04
Methylene chloride	0.01	5	980	630	2,700	1,700	270	180
Tetrachloroethene	0.25	5	0.01	0.008	0.04	0.02	0.03	0.02
Nitrogen as nitrate + nitrite	0	10,000	44,500	29,000	79,900	52,000	79,900	52,000
Post-Remediation Long Term Recharge Rate 4 mm/yr; Source Length = 2 x Length of Waste Site								
Benzene	0.05	5	0.09	0.06	0.2	0.1	0.2	0.1
Carbon tetrachloride	0.15	3.4 ^a	2.6	1.5	4.5	2.6	5.0	2.9
Chloroform	0.05	80 ^b	0.5	0.3	1.2	0.7	0.8	0.5
Ethylbenzene	0.20	700	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04
Methylene chloride	0.01	5	1,300	850	3,600	2,300	380	250

**Table E5-16. Results of 216-Z-18 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K _d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Tetrachloroethene	0.25	5	0.2	0.1	0.6	0.4	0.5	0.3
Nitrogen as nitrate + nitrite	0	10,000	60,500	39,100	109,000	70,100	109,000	70,100
Post-Remediation Long Term Recharge Rate 22 mm/yr								
Benzene	0.05	5	0.1	0.06	0.2	0.1	0.3	0.2
Carbon tetrachloride	0.15	3.4 ^a	31	18	53	31	60	35
Chloroform	0.05	80 ^b	0.9	0.5	1.8	1.0	1.2	0.7
Ethylbenzene	0.20	700	0.2	0.1	0.2	0.1	0.2	0.1
Methylene chloride	0.01	5	2,100	1,200	5,800	3,400	570	350
Tetrachloroethene	0.25	5	9.7	5.6	29	17	23	14
Nitrogen as nitrate + nitrite	0	10,000	88,900	53,000	160,000	95,200	160,000	95,200
Post-Remediation Long Term Recharge Rate 63 mm/yr								
Benzene	0.05	5	0.3	0.2	0.7	0.4	0.7	0.4
Carbon tetrachloride	0.15	3.4 ^a	77	46	130	79	150	89
Chloroform	0.05	80 ^b	2.1	1.3	4.3	2.6	3.0	1.8
Ethylbenzene	0.20	700	0.9	0.5	1.2	0.7	1.2	0.7
Methylene chloride	0.01	5	5,000	3,000	13,800	8,200	1,500	890
Tetrachloroethene	0.25	5	23	14	69	41	56	33
Nitrogen as nitrate + nitrite	0	10,000	210,000	124,000	377,000	222,000	377,000	222,000

Notes:

216-Z-18 Crib is approximately 53 m (174 ft) long. 1,000-year timeframe.

a. The EPA MCL for CT is 5 $\mu\text{g}/\text{L}$; the final cleanup level in the 200-ZP-1 Record of Decision is 3.4 $\mu\text{g}/\text{L}$ (EPA et al., 2008, *Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington*).

b. The EPA MCL for total trihalomethanes, which include bromodichloromethane, bromoform, and chloroform, is 80 $\mu\text{g}/\text{L}$.

Table E5-17. Results of 216-Z-9 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater

Contaminant	K_d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
Post-Remediation Long Term Recharge Rate 0.5 mm/yr; Source Length = 2 x Length of Waste Site								
Contaminant	K_d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	5 m	10 m	5 m	10 m	5 m	10 m
1,1,2,2-Tetrachloroethane	0.05	NP ^a	0.008	0.004	0.01	0.007	0.01	0.007
1,1,2-Trichloroethane	0.05	5	0.005	0.003	0.01	0.006	0.02	0.01
1-Butanol	0.01	NP ^b	130	72	230	130	300	170
Bromodichloromethane	0.05	80 ^c	0.003	0.002	0.006	0.003	0.01	0.006
Bromoform	0.10	80 ^c	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4
Carbon tetrachloride	0.15	3.4 ^d	0.0004	0.0002	0.0007	0.0004	0.001	0.0006
Chloroform	0.05	80 ^c	1.1	0.7	4.6	2.7	2.9	1.7
Methylene chloride	0.01	5	1.6	0.9	2.6	1.5	5.3	3.1
Tetrachloroethene	0.25	5	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4
Trichloroethene	0.10	5	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4
Technetium-99	0	900	7,200	4,200	10,600	6,100	10,600	6,100
Hexavalent chromium	0	50	20	12	23	13	23	13
Nitrogen as nitrate + nitrite	0	10,000	83,500	48,700	120,000	70,300	166,000	97,700
Post-Remediation Long Term Recharge Rate 4 mm/yr; Source Length = 2 x Length of Waste Site								
1,1,2,2-Tetrachloroethane	0.05	NP ^a	0.08	0.05	0.1	0.08	0.1	0.08
1,1,2-Trichloroethane	0.05	5	0.05	0.03	0.1	0.05	0.2	0.1
1-Butanol	0.01	NP ^b	160	92	290	170	370	210
Bromodichloromethane	0.05	80 ^c	0.03	0.02	0.05	0.03	0.1	0.06
Bromoform	0.10	80 ^c	1E-04	<1E-4	3E-04	2E-04	5E-04	3E-04
Carbon tetrachloride	0.15	3.4 ^d	0.007	0.004	0.01	0.07	0.02	0.01
Chloroform	0.05	80 ^c	3.3	1.9	9.5	5.4	8.4	4.7
Methylene chloride	0.01	5	2.0	1.2	3.2	1.9	6.6	3.9
Tetrachloroethene	0.25	5	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4
Trichloroethene	0.10	5	2E-04	1E-04	4E-04	2E-04	6E-04	3E-04
Technetium-99	0	900	8,900	5,200	13,100	7,500	13,100	7,500
Hexavalent chromium	0	50	21	12	24	14	24	14
Nitrogen as nitrate + nitrite	0	10,000	107,000	62,800	153,000	90,300	204,000	121,000

Table E5-17. Results of 216-Z-9 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater

Contaminant	K_d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
Post-Remediation Long Term Recharge Rate 22 mm/yr Source Length = Length of Waste Site								
Contaminant	K_d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	5 m	10 m	5 m	10 m	5 m	10 m
1,1,2,2-Tetrachloroethane	0.05	NP ^a	0.3	0.2	0.5	0.3	0.5	0.3
1,1,2-Trichloroethane	0.05	5	0.2	0.09	0.3	0.2	0.6	0.3
1-Butanol	0.01	NP ^b	220	130	410	230	520	300
Bromodichloromethane	0.05	80 ^c	0.09	0.04	0.2	0.1	0.3	0.2
Bromoform	0.10	80 ^c	0.1	0.08	0.3	0.2	0.5	0.3
Carbon tetrachloride	0.15	3.4 ^d	110	63	250	140	290	160
Chloroform	0.05	80 ^c	11	6.5	27	15	28	16
Methylene chloride	0.01	5	3.0	1.7	4.9	2.8	10	5.7
Tetrachloroethene	0.25	5	0.05	0.03	0.1	0.05	0.1	0.05
Trichloroethene	0.10	5	0.2	0.1	0.4	0.2	0.7	0.4
Technetium-99	0	900	14,000	8,100	20,500	11,800	20,500	11,800
Hexavalent chromium	0	50	17	9.8	20	11	20	11
Nitrogen as nitrate + nitrite	0	10,000	157,000	89,900	224,000	128,000	288,000	165,000
Post-Remediation Long Term Recharge Rate 63 mm/yr Source Length = Length of Waste Site								
1,1,2,2-Tetrachloroethane	0.05	NP ^a	0.6	0.4	1.0	0.6	1.0	0.6
1,1,2-Trichloroethane	0.05	5	0.3	0.2	0.6	0.4	1.2	0.7
1-Butanol	0.01	NP ^b	450	260	820	480	1,000	610
Bromodichloromethane	0.05	80 ^c	0.2	0.1	0.4	0.2	0.7	0.4
Bromoform	0.10	80 ^c	0.3	0.2	0.6	0.3	1.1	0.6
Carbon tetrachloride	0.15	3.4 ^d	640	370	1,400	810	1,600	930
Chloroform	0.05	80 ^c	23	13	54	31	56	32
Methylene chloride	0.01	5	6.3	3.6	10	5.8	21	12
Tetrachloroethene	0.25	5	15	8.8	34	19	33	19
Trichloroethene	0.10	5	0.4	0.2	0.8	0.5	1.3	0.7
Technetium-99	0	900	26,700	15,500	39,1000	22,800	39,1000	22,800
Hexavalent chromium	0	50	35	20	40	23	40	23
Nitrogen as nitrate + nitrite	0	10,000	329,000	192,000	476,000	278,000	628,000	366,000

**Table E5-17. Results of 216-Z-9 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K_d (mL/g)	MCL ($\mu\text{g}/\text{L}$)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Notes:								
216-Z-9 Crib is approximately 27 m (88 ft) long. 1,000-year timeframe.								
a. There is no published EPA MCL specifically for 1,1,2,2-tetrachloroethane; there is a published EPA MCL for tetrachloroethane (5 $\mu\text{g}/\text{L}$).								
b. There is no published EPA MCL for 1-Butanol.								
c The EPA MCL for total trihalomethanes, which include bromodichloromethane, bromoform, and chloroform, is 80 $\mu\text{g}/\text{L}$.								
d. The EPA MCL for CT is 5 $\mu\text{g}/\text{L}$; the final cleanup level in the 200-ZP-1 Record of Decision is 3.4 $\mu\text{g}/\text{L}$ (EPA et al., 2008, <i>Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington</i>).								

**Table E5-18. Results of 216-A-8 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K_d (mL/g)	MCL (pCi/L or mg/L)	Length of Contamination Source Mixing Zone					
			Full Length of Crib		Half Length of Crib		Quarter Length of Crib	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 4 mm/yr (Unlimited Timeframe)								
Carbon-14	0	2,000	2,400	1,900	940	870	NE	NE
Technetium-99	0	900	1,300	1,000	510	470	NE	NE
Nitrogen as nitrate + nitrite	0	10	0.9	0.7	0.3	0.3	NE	NE
Hexavalent chromium	0	0.050	0.009	0.007	0.004	0.003	NE	NE
Post-Remediation Long Term Recharge Rate 4 mm/yr (1,000 year Timeframe)								
Carbon-14	0	2,000	1,500	1,200	570	530	NE	NE
Technetium-99	0	900	690	550	260	240	NE	NE
Nitrogen as nitrate + nitrite	0	10	0.5	0.4	0.2	0.2	NE	NE
Hexavalent chromium	0	0.050	0.006	0.004	0.002	0.002	NE	NE
Post-Remediation Long Term Recharge Rate 22 mm/yr (Unlimited Timeframe)								
Carbon-14	0	2,000	7,200	5,800	2,800	2,600	NE	NE
Technetium-99	0	900	3,500	2,800	1,400	1,300	NE	NE
Nitrogen as nitrate + nitrite	0	10	2.3	1.9	0.9	0.8	NE	NE
Hexavalent chromium	0	0.050	0.02	0.02	0.009	0.009	NE	NE

**Table E5-18. Results of 216-A-8 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K_d (mL/g)	MCL (pCi/L or mg/L)	Length of Contamination Source Mixing Zone					
			Full Length of Crib		Half Length of Crib		Quarter Length of Crib	
Post-Remediation Long Term Recharge Rate 63 mm/yr (Unlimited Timeframe)								
Carbon-14	0	2,000	NE	NE	NE	NE	2,200	2,300
Technetium-99	0	900	NE	NE	NE	NE	1,100	1,100
Nitrogen as nitrate + nitrite	0	10	NE	NE	NE	NE	0.7	0.7
Hexavalent chromium	0	0.050	NE	NE	NE	NE	0.007	0.007

Notes:

216-A-8 Crib is approximately 260 m (853 ft) long.

NE = not evaluated

The model results representing conditions associated with construction and placement of an ET barrier at 216-Z-1A Crib indicate that the presence of the barrier would reduce the maximum concentration of CT in groundwater to less than the MCL. The maximum concentration of nitrogen as nitrate and nitrite would be only slightly over the MCL during the 1,000-year evaluation period. Even with the installation of an ET barrier at 216-Z-1A, the model results indicate that the maximum concentration of methylene chloride would still be well over the MCL. The model results for the 216-Z-18 Crib indicate that the presence of the barrier would reduce the maximum concentrations of methylene chloride and nitrogen as nitrate and nitrite by approximately 25 percent, but the maximum concentrations of both COPCs would still exceed the respective MCLs by a large margin. Similarly, the model results for the 216-Z-9 Crib indicate that the presence of the barrier would reduce the maximum concentrations of Tc-99 and nitrogen as nitrate and nitrite by approximately 20 percent, but the maximum concentrations of both COPCs would still exceed the respective MCLs by a large margin.

E5.5 Summary and Conclusions

The results of the modeling provide an indication as to the amount of remediation necessary to achieve protection of groundwater at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs. The two most probable end states after remediation include naturally or artificially enhanced reclamation of the shrub-steppe surface and vegetation (long-term recharge rate of 4 mm/yr after 30 years of 8 mm/yr recharge). The other end state is an ET surface barrier that reduces or eliminates percolation of water through the contaminated soil (0.5 mm/yr for 500 years and 1.0 mm/yr thereafter). The model results for 216-Z-1A Crib indicate that the maximum concentration of CT in groundwater exceeds the MCL during the evaluation period if the surface is revegetated, but does not exceed the MCL during the evaluation period if an ET surface barrier is constructed. The model results for methylene chloride and nitrogen as nitrate and nitrite at 216-Z-1A Crib indicate that the maximum concentrations exceed the MCL during the evaluation period whether or not an ET surface barrier is constructed. However, the results indicate that the maximum concentration of nitrogen as nitrate and nitrite is only slightly above the MCL with the barrier in place. The model results for the 216-Z-18 Crib indicate that the maximum concentrations of methylene chloride and nitrogen as nitrate and nitrite exceed the MCL by a large margin during the

evaluation period whether or not an ET surface barrier is constructed. Similarly, the model results for the 216-Z-9 Crib indicate that the maximum concentrations of Tc-99 and nitrogen as nitrate and nitrite exceed the MCL by a large margin whether or not an ET surface barrier is constructed. The modeling results for 216-A-8 indicate that none of the COPCs exceed the MCL during the evaluation period if the shrub-steppe vegetation reclaims the surface.

If long-term post-remediation recharge remains 22 mm/yr indefinitely, e.g., no efforts to reestablish natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the surface, then the model results indicate that the maximum groundwater concentrations of the COPCs during the 1,000-year evaluation period are greater than concentrations in the reference case results. However, the maximum groundwater concentration of only a few COPCs increase from below the MCL at 4 mm/yr long-term recharge rate to over the MCL at 22 mm/yr long-term recharge rate. The list of COPCs with modeled concentrations in groundwater exceeding the MCLs at 22 mm/yr long-term recharge rate does not change for 216-Z-1A but it does increase for the 216-Z-18, 216-Z-9, and 216-A-8 Cribs, relative to the reference case results. For the 216-Z-18 Crib, the modeling results indicate that the maximum concentrations of CT and tetrachloroethene exceed the MCLs if the long-term recharge rate remains 22 mm/yr indefinitely. For the 216-Z-9 Crib, the modeling results indicate that the maximum concentration of CT exceeds the MCL with the higher long-term recharge rate. For the 216-A-8 Crib, the modeling results indicate that the maximum concentrations of carbon-14 and Tc-99 exceed the MCLs with the higher long-term recharge rate if the contamination extends beyond one-half the length of the crib. The trend in the results indicates that the maximum concentrations would not exceed the MCLs if the contamination extended approximately one-quarter the length of the crib.

According to the modeling results calculated using best-estimate parameter values for evaluating long-term impacts to groundwater, potentially adverse impacts appear to exist at three of the waste sites: 216-Z-1A, 216-Z-18, and 216-Z-9. There are only a small number of contaminants at each waste site, from among the approximately 70 COPCs evaluated, that potentially pose adverse risk to groundwater: nitrogen at all three cribs, methylene chloride, which is a degradation product of CT, at 216-Z-1A and 216-Z-18 Cribs, and Tc-99 at 216-Z-9 Crib. The COPCs identified in the model results as having adverse impacts to groundwater may not in actuality pose an adverse risk to groundwater due to the conservatism included in the source term concentrations used in the modeling (Section E4).

The potential impacts to groundwater from CT and/or methylene chloride at the 216-Z-1A and 216-Z-18 Cribs may be much less than estimated because the contaminant concentration estimates for the discrete depth intervals are based on data collected prior to the onset of SVE operations. In addition, the methylene chloride data with the highest concentration values appear to be suspect (Section E4). The data collected near 216-Z-9 Crib include data collected both before the onset of SVE operations and data collected as recently as 2006. These data indicate that the SVE has reduced the concentration levels of the VOCs in the soil by more than a factor of 10. Operation of the SVE system has decreased the extent of vadose zone contamination of the volatile COPCs in the area around the 216-Z-9 Crib to where it appears to be less than the dimensions of the waste site footprint. The modeling results indicate that none of the volatile COPCs associated with the 216-Z-9 Crib contamination pose an adverse risk to groundwater within the 1,000-year evaluation period. Without more recent data to estimate the contaminant concentration estimates for the discrete depth intervals for the 216-Z-1A and 216-Z-18 Cribs, the concentration estimates are based on sample measurements collected prior to and unaffected by SVE operations. If the SVE has had the same affect around the 216-Z-1A and 216-Z-18 Cribs as it has had around 216-Z-9 Crib, then the model input estimates for both the discrete depth interval concentrations and the lateral extent of the VOC are highly biased conservatively. CT and methylene chloride may not actually pose an adverse risk to groundwater.

Additionally, the methylene chloride data with the highest concentration values appear suspect (possibly resulting from laboratory contamination). Methylene chloride is a known laboratory contaminant and the data do not follow the distribution pattern of the other volatile COPCs. The highest concentrations of other volatile organic COPCs (e.g. 1,1-dichloroethane, CT, chloroform) occur in data collected from within the waste site footprints, whereas the highest concentrations of methylene chloride occur outside the waste site footprints. If the sample results were affected by laboratory contamination, then the model results are not representative of the vadose zone contamination.

The highest COPC concentrations appear to occur directly beneath or very close to the footprints of the waste sites (e.g., the highest contaminant concentrations at 216-Z-9 Crib appear to be within about 10 m [33 ft] of the southern edge of the crib). The overall lateral extent of non-organic COPCs in the subsurface appears to be contained within an area that extends approximately 2 times the dimensions of the waste site footprint. In the modeling evaluations of the Z-area cribs that incorporate the best estimate parameters, the extent of contamination is approximately 2 times the dimensions of the waste site footprint. Applying highly biased average concentrations, compared to more representative approximations of the average for the entire extent of contamination, results in an overestimation of the potential impacts to groundwater.

The model results may overestimate the potential impacts to groundwater at all of the waste sites for the non-organic COPCs (e.g., nitrogen and Tc-99). As discussed in Section E4, the estimates of average contaminant concentration in the discrete depth intervals used in the models include a high level of uncertainty. The estimates are typically based on only one to four data points within a depth interval. These estimates are extrapolated to approximate the contaminant concentration throughout the extent of contamination. These concentration estimates include a very high bias toward the maximum concentrations observed in the plume because almost all of the non-organic COPC data were collected from locations beneath or very close to the footprints of the waste sites. These locations were selected for characterizing the maximum amount of contamination in the soil. Thus, the averages may be more representative of the conditions in the plume where the concentrations are the highest, rather than the conditions throughout the extent of contamination. This introduces two factors that bias the results conservatively: the average concentrations are calculated using data points biased toward the maximum values occurring in the plume, and this average concentration is applied to the entire length of contamination in the model (i.e., two times the dimensions of the waste site footprint).

E5.5.1 Implications for Barrier Effectiveness

The main implication of these results for the four cribs is that recharge reduction to levels of about 0.5 mm/yr produce efficiencies in decreasing peak contaminant concentrations in groundwater, and consequently reduction in peak groundwater arrival times, only slightly greater than those obtained with natural vegetation conditions. Thus, it is indicated that the primary risk mitigation objectives of the “ET-barrier/cover” remedy may well be achieved by the restoration of the site to natural vegetation conditions, which is estimated to occur in a period of ≤ 30 years (DOE/RL-2007-34). The cost benefit of an ET barrier for the mitigation of groundwater impacts of vadose zone contamination remaining at the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs may, therefore, be minimal compared to restoration of the site(s) to natural conditions, in conjunction with an ongoing remedy such as monitored natural attenuation.

E5.5.2 Modeling QA/QC

The vadose zone fate and transport calculations were performed using the STOMP Version 3.2 code, HSI identification number 2471. DOE/RL-2007-34 contains a summary of the main model attributes and code selection criteria that serve as the basis for the demonstration of the adequacy of the STOMP code for use in vadose zone modeling at the Hanford Site. The results of the evaluation in DOE/RL-2007-34

show that the STOMP code is capable of meeting or exceeding the identified attributes and criteria. The comparison of the code selection criteria to the STOMP code capabilities indicates the STOMP code is capable of simulating all of the necessary FEPs, and that STOMP meets all of the other required code selection criteria. Section 6.4.1 of DOE/RL-2007-34 addresses code selection criteria, including QA documentation of verification studies for specific model attributes (e.g., unsaturated flow, solute transport, infiltration, and drainage), and includes a discussion of other code related criteria (i.e., inter-code comparisons, hardware requirements, solution methodology, dimensionality, and output capability).

STOMP was executed on the RANSAC Linux^{®2} Cluster (ransac-0.pnl.gov) that is managed by PNNL. Excel³ spreadsheets were used to calculate contaminant inventory values and approximate contaminant distributions, calculate crib discharge volumes, interpolate crib dimensions onto the numerical grid, calculate dispersivity values, and evaluate the results produced by STOMP.

The results of CHPRC acceptance testing (CHPRC-00515, *STOMP Acceptance Test Report*,) demonstrate that the STOMP software is acceptable for its intended use by the CHPRC. Installations of the software are operating correctly, as demonstrated by the RANSAC Linux Cluster system producing the same results as those presented for selected problems from PNNL-11216, *STOMP: Subsurface Transport Over Multiple Phases Application Guide*.

² Linux is the registered trademark of Linus Torvalds in the U.S. and other countries.

³ Excel and Windows are registered trademarks of Microsoft Corporation in the United States and other countries.

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